106

ORDNANCE PAMPHLET 1140

BASIC FIRE CONTROL MECHANISMS

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SEPTEMBER 1944

RESTRICTED

NAVY DEPARTMENT
BUREAU OF ORDNANCE
WASHINGTON 25, D. C.

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F. I. Entwistle
Acting Chief of Bureau

OP 1140 CHANGE 1
9 March 1949

1 Page ______ Page 1

ORDNANCE PAMPHLET 1140
is changed as follows:

BASIC FIRE CONTROL MECHANISMS

1. Insert this change sheet between cover and title page.
2. Replace page 7 with new page 7 attached.
3. Insert section 7, pages 373 to 424, attached.
4. Cancel INDEX page 372; remove and destroy INDEX pages 373 through 378; cancel INDEX page 379. A corrected index has not been prepared. Delete page numbers but retain distribution list (original page 380) and NOTES (original pages 381 through 384).

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ORDNANCE PAMPHLET 1140

BASIC FIRE CONTROL MECHANISMS

1. Ordnance Pamphlet 1140 explains the mechanical and electromechanical basic mechanisms used by Ford Instrument Company and Arma Corporation in fire control equipment built for the United States Navy. It is bound in loose-leaf form with provision for expansion in case it is desired to add material at a later date.

2. This publication is a basic text and reference book, providing a source of general information on the basic mechanisms of fire control equipment. It is considered that Ordnance Pamphlet 1140 is a prerequisite to the study of any Ordnance Pamphlet on the mechanical computing instruments for fire control equipment.

3. Ordnance Pamphlet 1140 supersedes Ordnance Data 1661, which should be destroyed.

4. This publication is RESTRICTED and should be handled in accordance with Article 76, U. S. Navy Regulations, 1920.

G. F. Hussey, Jr.

G. F. HUSSEY, JR.
Rear Admiral, U. S. Navy
Chief of the Bureau of Ordnance

Prepared For
THE BUREAU OF ORDNANCE
by the
FORD INSTRUMENT COMPANY, INC.
Long Island City, New York

QUICK REFERENCE INDEX

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INTRODUCTION

The basic mechanisms described in this book were especially developed over a period of about 30 years to do a highly specialized job. That job is to *solve mechanically the mathematics for surface and anti-aircraft fire control.* These basic mechanisms make the necessary computations to point the guns and set the fuzes to hit fast moving targets with shells fired from the deck of a ship which is moving, pitching, and rolling. To aim the guns correctly under these conditions about 25 things must be taken into account all at the same time. These include target speed, climb, and direction; target range, elevation, and bearing; own ship speed and course; wind speed and direction; pitch and roll; and initial shell velocity.

If the enemy were to announce six or eight hours beforehand just where the target would be at a particular instant and just how it would be moving, a lightning mathematician would be able to calculate where to point the guns to hit it at that one instant. *But,* the results would be good only for one instant.

Instead of going through the mathematical calculations necessary to make each shot count, a ship might try to throw out enough exploding shells to hit the target almost by pure chance. That is, it might throw out a barrage of shells and let the target fly into them. This type of fire is effective against some types of air attack, but it is far from a satisfactory answer to the problem of aiming the guns.

What is needed is an instrument which will predict quickly and accurately what will happen while the shell is in the air, compute the necessary corrections for the guns, and in addition continuously correct the guns for the effects of pitch and roll of own ship. As soon as a target is picked up, this instrument must be able to solve the fire control problem in a few seconds and thereafter it must keep on solving the problem *continuously* and *accurately* as own ship and target move in relation to each other.

At first it might seem that such an instrument would be far too complex for anyone but an engineer to understand, but that is not true. Actually it is a collection of standard mechanisms and parts assembled together inside a case. Each mechanism or part has a particular job to do in solving the fire control problem. This book is intended to explain what these mechanisms are and what each can do. By studying each unit in turn, learning what it can do and how it does it, and how it can be used with the other units, it is possible to learn many of the fundamental things that one must know to operate and maintain the Computers, Range Keepers and other instruments. These include:

Computer Mark 1, for the 5″ guns, and certain others.
Range Keeper Mark 10, for the 5″ guns.
Range Keeper Mark 8, for main battery guns.
Computer Mark 3, stand-by for the Mark 8.
Torpedo Data Computer Mark 3 and Mark 4.

SECTION 1

BASIC INFORMATION

A certain amount of basic information is necessary to understand fire control mechanisms. This information is summarized in the three chapters which make up this section.

1 The chapter, "Basic Mechanics," introduces a number of mechanical elements common to most of the mechanisms. These mechanical elements include gears, shafts, bearings and clamps. This chapter also explains several basic mechanical ideas such as "gear ratios," "shaft values" and "shaft positions."

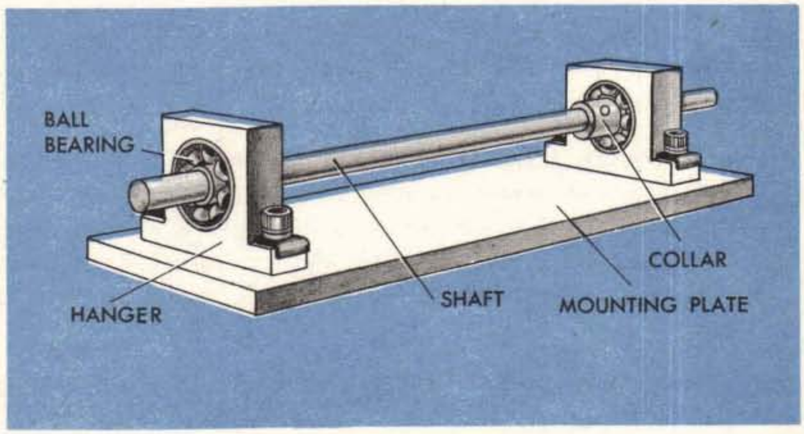
2 "Basic Mathematics" briefly summarizes the mathematical operations which are more frequently used in fire control. This chapter does not try to teach mathematics, but assumes that the principles it reviews are already familiar. Later explanations of the computing mechanisms will be based largely on these mathematical principles.

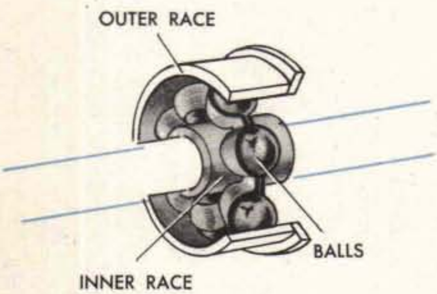
3 "Basic Setting Information" describes the more important setting tools and procedures commonly used in setting the various mechanisms. This chapter supplies the basic information which will be needed to understand the setting instructions included with the description of each mechanism.

4 The basic information about magnetism and electricity needed for Section 3 on Electromechanical Units is furnished in the first chapter of that section.

BASIC MECHANICS

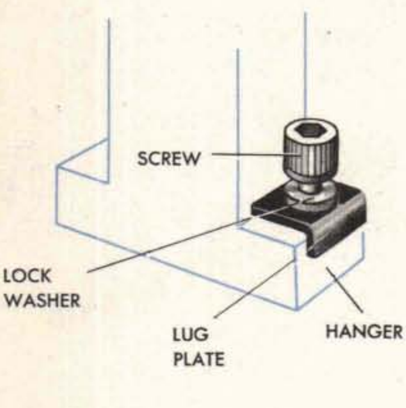
SHAFTS, HANGERS, MOUNTING PLATES, BEARINGS and COUPLINGS





Here is a typical shaft assembly.
The mounting plate is used to support the whole assembly inside the equipment. The hangers are used to support individual shafts.

The hangers are held in place by screws. Lock washers keep the screws from working loose. Lug plates keep the lock washers from digging into the softer hanger metal.
The shaft is free to turn on ball bearings mounted in the hangers.



A ball bearing has an inner race and an outer race. The outer race is fitted snugly into the hole in the hanger. The inner race turns with the shaft. When the shaft turns, the balls roll between the two races. There is no sliding motion between any of the parts, so there is practically no wear and no drag in this kind of bearing.

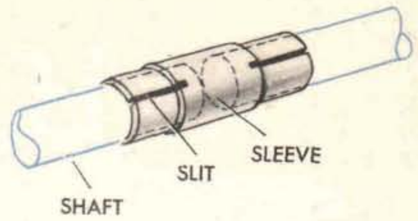
The shaft is held in position endwise by collars. These are pinned to the shaft so that they can neither turn ON the shaft nor slip ALONG the shaft.

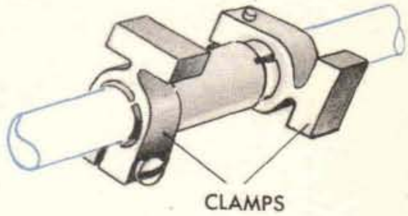
There are three principal devices used to join shafts end to end:

1 A sleeve coupling is used to join two closely aligned shafts usually where an adjustment of the shaft relationship is necessary. It consists of a sleeve over the ends of the two shafts, with a clamp over each end of the sleeve.

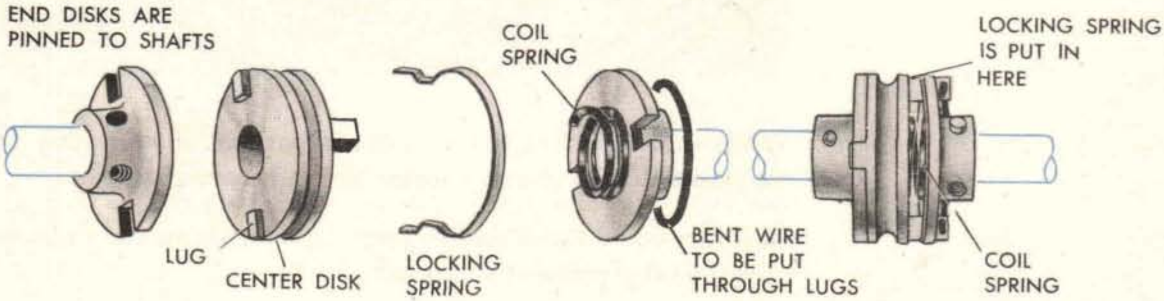
The ends of the sleeve are slit so that the clamps can hold the sleeve tightly on the shafts.

When the clamps are tight, the two shafts are held firmly together in the sleeve and will turn as one.





2 An Oldham coupling is used to eliminate the necessity of perfect alignment between two shafts. It is also used between two shafts that must be readily connected or disconnected. Occasionally it is used as an expansion joint in a long shaft.



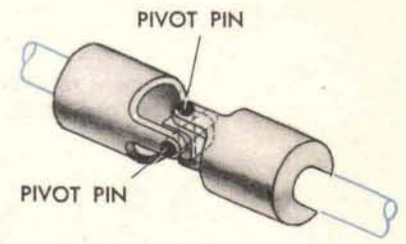
The Oldham coupling consists of a pair of disks pinned to the ends of the shafts, and a third center disk, with lugs, which fits between the two.

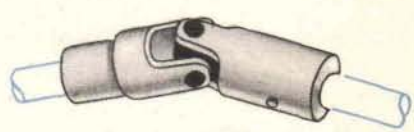
The lugs on the center disk fit into slots in the other two disks, enabling one shaft to drive through the disks to the other shaft.

The center disk is mounted on one of the side disks, and is held away from this disk by a coil spring. The center disk lugs on this side are extended, and a bent wire is run through the ends of the lugs to hold the assembly together.

When the coil spring is compressed, the center disk can be moved free of the other side disk, so that the two shafts can be disconnected.

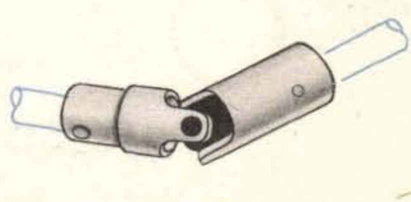
Aboard ship, jarring may occasionally compress these coil springs and disconnect the shafts. To prevent this, a locking spring is used which fills the space between the center disk and side disk. The coil spring cannot be compressed while the locking spring is in place.



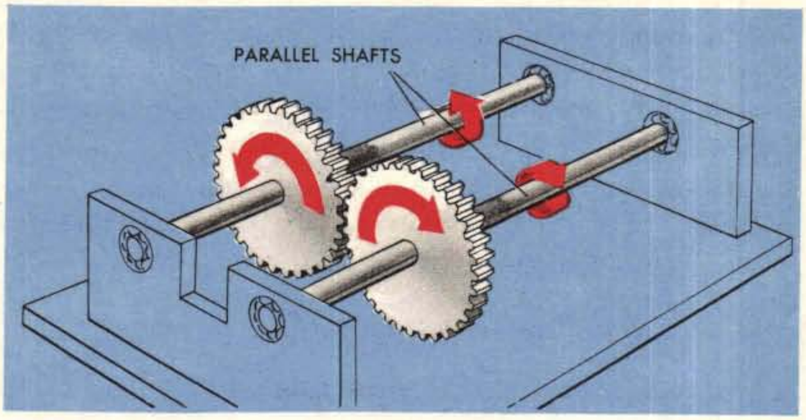


3 A universal joint is often used to connect shafts at an angle to each other.

Because of the two pivot pins in this joint, one shaft can drive the other even though the angle between the two is as great as 25°.

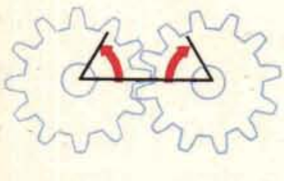


GEARS



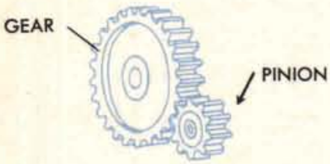
When shafts are not in line, but are parallel, motion may be transmitted from one to another through spur gears.

Gears are wheels with mating teeth cut in them so that one can turn the other without slippage.

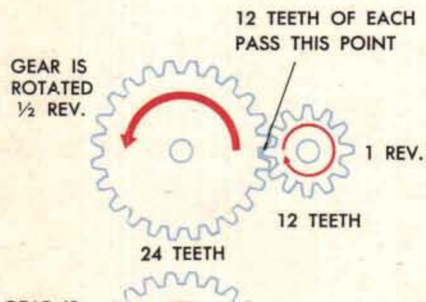


Straight spur gears are used to connect parallel shafts. Their teeth are cut parallel to the axis of rotation.

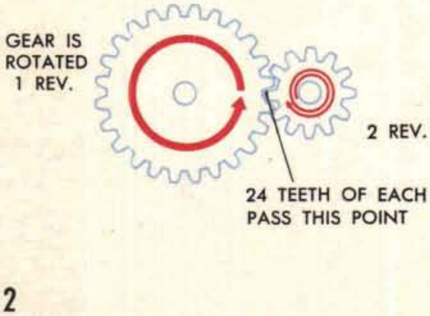
If two mating gears are the same size, they will have the same number of teeth. One revolution of the driving gear will turn the driven gear one revolution, because each tooth of the driving gear will push one tooth of the driven gear across the line between their centers.



If two gears are of different sizes the smaller one is usually called a pinion.

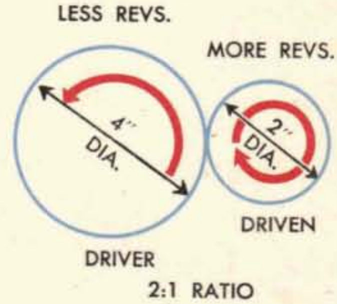


When a gear and a pinion mesh together, their shafts turn at different speeds.



Suppose that a gear has twice as many teeth as its pinion. For instance, the gear has 24 teeth and the pinion 12. If the gear is driving, one revolution of the gear will turn the pinion two revolutions. The pinion will turn TWO WHOLE revolutions for every ONE revolution of the gear.

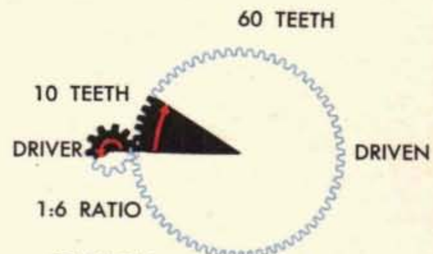
The ratio between the number of teeth on the driving gear and the number of teeth on the driven gear is called the *gear ratio.* Since it is comparatively easy to count gear teeth, this is perhaps the simplest way to establish the gear ratio.



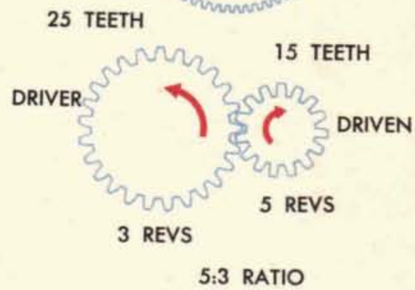
However, since meshing gear teeth are of the same size, dividing the *circumference* of the driving gear by the *circumference* of the driven gear will also provide the gear ratio. Because the corresponding parts of circles are proportional, dividing the *diameter* of the driving gear by the *diameter* of the driven gear will also produce the gear ratio.

$$\text{GEAR RATIO} = \frac{\text{Teeth of } \textit{driver}}{\text{Teeth of } \textit{driven}} = \frac{\text{Diameter of } \textit{driver}}{\text{Diameter of } \textit{driven}}$$

A gear with a 4″ diameter driving a gear with a 2″ diameter will have a ratio of 2:1. The pinion will rotate twice as fast as the driver.

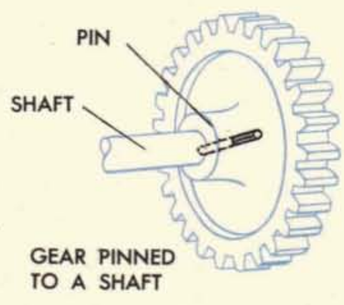


Here are a pair of gears with a 1:6 ratio. The driving pinion has 10 teeth, and the gear 60. The pinion shaft turns 6 times as fast as the gear shaft it drives.

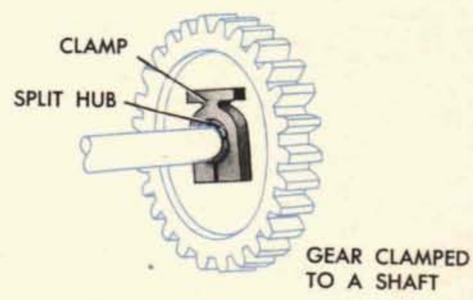


Here are a pair of gears with a 5:3 ratio. The driving gear has 25 teeth, and the driven pinion has 15. The gear shaft makes 3 revolutions, while the pinion shaft is driven 5 revolutions.

There are several ways of holding a gear to its shaft. To permanently join the two parts, a pin can be put through the hub and the shaft. To permit adjustment or simplify assembly, the gear may be held by a clamp which tightens a split gear hub on the shaft.



GEAR PINNED TO A SHAFT



GEAR CLAMPED TO A SHAFT

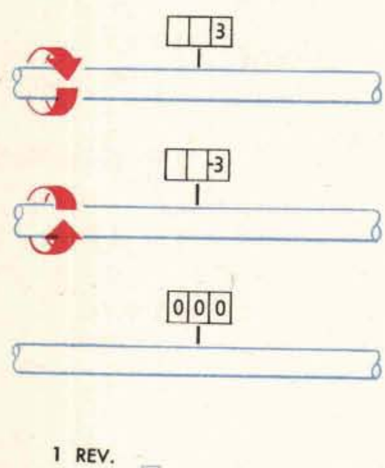
SHAFTS CARRY VALUES

A computer needs a variety of information to help it solve the fire control problem. It receives this information as *values of various quantities* such as yards of Range, degrees of Elevation, and knots of Ship Speed. Most of these quantities are continually changing in value. At every instant, however, each of these quantities has a definite numerical *value*. These values are used in a computer to position the computing mechanisms.

As each of the input values changes, the values of several of the computed quantities will also change. All of these changing values must be carried instantaneously and continuously to all the mechanisms affected by that particular quantity.

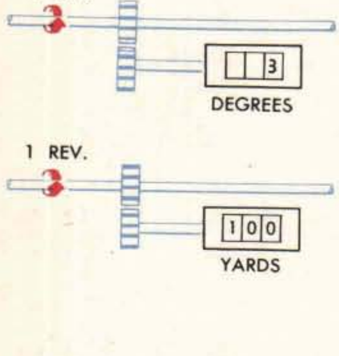
THE FUNCTION OF SHAFTS IN A COMPUTER IS, BY TURNING, TO CARRY THESE CHANGING VALUES FROM ONE MECHANISM TO ANOTHER INSTANTANEOUSLY AND CONTINUOUSLY.

Shaft value



Any turning of a shaft changes the value of the particular angle, speed, or distance, represented by that shaft. Rotation in one direction increases the value on the shaft. Rotation in the opposite direction decreases the value. Usually a shaft will make many revolutions when there is a large change in the value of the quantity it is carrying.

Almost every shaft has a zero position. *Zero position for a shaft is the position where the value of the quantity represented by that shaft is zero.*



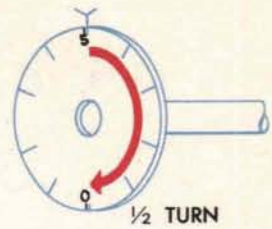
One revolution of a shaft can represent any convenient amount of value. For example, on some of the elevation shafts one revolution represents 3° of elevation. These shafts have a shaft value of 3°. On some of the range shafts one turn may represent 100 yards of range. These range shafts then have shaft values of 100 yards.

SHAFT VALUE IS THE VALUE THAT A SHAFT CARRIES IN ONE REVOLUTION, THAT IS, THE VALUE PER REVOLUTION.

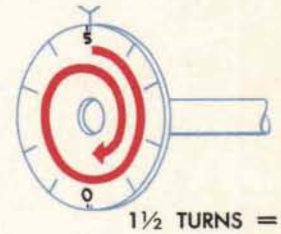
In most other machines, shafts and gearing are used mainly to carry power, and gear ratios are usually chosen to vary the shaft speed and torque. However, in mechanical fire control computers, the shafts' main job is *to carry throughout the computer the changing values of all the needed quantities.*

The total value on the shaft

A dial fixed directly to a shaft with its zero position matched to the shaft zero position will only show the total value carried by that shaft during one revolution. If the shaft has a shaft value of 10° and is turned one half a revolution away from the zero position, the *total value* carried by that shaft will be 5°. If the shaft is now turned one complete revolution in the same direction, the dial will again read 5° although the shaft is one and one-half revolutions *away from the zero position and the total value on the shaft is now 15°*. The total value always depends on the number of revolutions the shaft is away from its zero position.



½ TURN



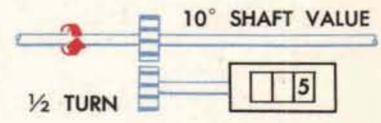
1½ TURNS = 15°
DIAL AT 5°

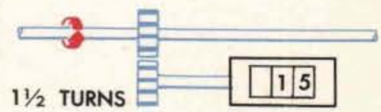
TOTAL VALUE IS THE SHAFT VALUE MULTIPLIED BY THE NUMBER OF REVOLUTIONS THE SHAFT IS POSITIONED AWAY FROM ITS ZERO POSITION.

How total values are read

Total value can be read on a counter because a counter geared to the shaft can show both the number of turns and the fraction of a turn the shaft is away from its zero position.

Suppose a counter is geared to a shaft with a 10° shaft value. The counter is adjusted to read zero at the shaft zero position. When the shaft is turned one-half a revolution to increase the value, the counter will read 5°. If the shaft is now turned one complete revolution in the same direction, the counter will read 15°. If the shaft is turned one and one-half revolutions in the opposite direction to decrease the total value, the counter will again read zero, because the shaft has been returned to its zero position.

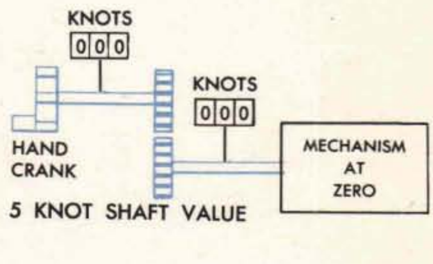




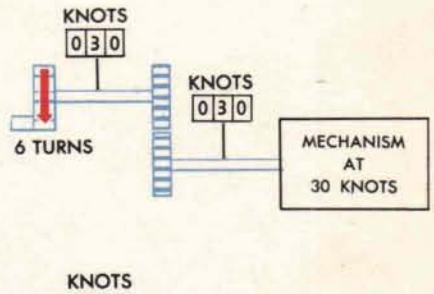
How the shafts carry total values

Here is a simple shaft line for putting values of Ship Speed into a computing mechanism.

A handcrank positions a shaft and counter. The value on the handcrank shaft is transferred by a pair of equal spur gears to the input shaft which positions the mechanism. The mechanism is set at its zero position. This positions the shaft at its zero position and the counter is adjusted to read zero. The shaft value in this example is 5 knots, so that every time the operator turns the handcrank one revolution he increases or decreases the input value to the mechanism by 5 knots.

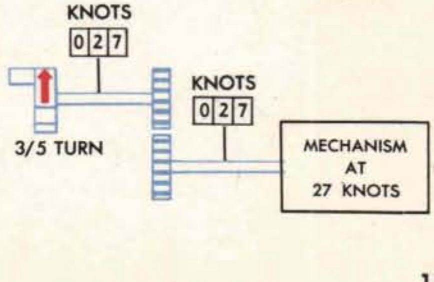


The total value put into the mechanism may be read on the counter. This value may be increased or decreased simply by turning the handcrank until the desired total value appears on the counter.



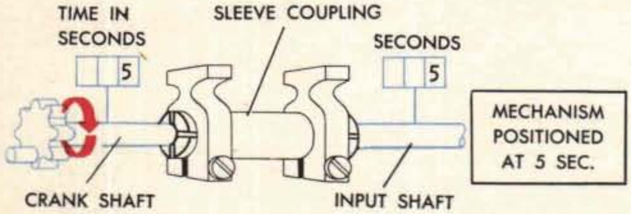
Suppose Ship Speed increases from 0 to 30 knots. The operator turns the crank until the counter shows 30 knots. This will require 6 turns of the handcrank. The shaft is now 6 turns away from its zero position. Therefore: 6 turns from zero position x 5° shaft value $= 30^\circ$ total value.

If ship speed decreases by 3 knots the handcrank must be turned 3/5 of a revolution in the opposite direction, to reduce the total value on the shaft, counter and mechanism to 27 knots.

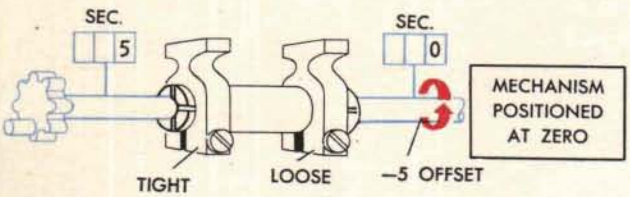


Using CLAMPS to ADD and SUBTRACT a CONSTANT

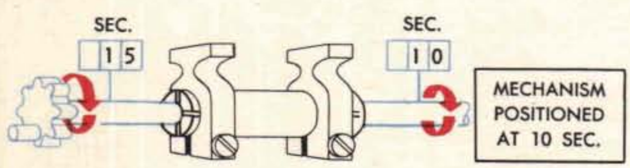
In solving a fire control problem it is sometimes necessary to add or subtract a constant from a value going into a mechanism. For example, some of the multipliers must be positioned by the values of the Time of Flight, *minus a constant*. In a case like this, the crank input is Time of Flight, but the mechanism is positioned for Time of Flight minus *K*. The constant *K* can be set into the transmission line by a sleeve coupling or a clamp gear.



Here is a sleeve coupling joining two shafts which must put Time of Flight in seconds, *minus a constant 5 seconds,* into the mechanism. Each shaft has a counter showing its position. Both shafts are positioned at 5 seconds.

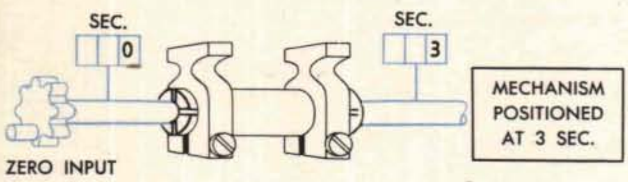


Now if one clamp is loosened, the unit input shaft can be turned till its counter reads zero, without moving the crank shaft. If this clamp is now tightened, with the value of 5 seconds on the crank shaft and zero on the input shaft, the two shafts will turn together when the crank is turned. But the input to the mechanism will always be five seconds *less* than the crank input.

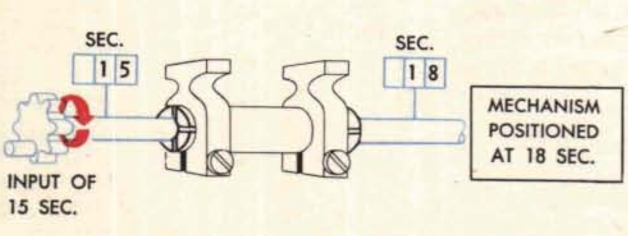


If the crank is turned to the position for a value of 15 seconds, the input to the mechanism will be 10 seconds, and so on.

This use of a clamp is called *putting a constant offset on the line*. The offset can be plus or minus.



Here's an example with a plus offset. The clamp is tightened when the crank shaft is in zero position and the input shaft at 3. The input to the mechanism will always be 3 more than the crank input value.



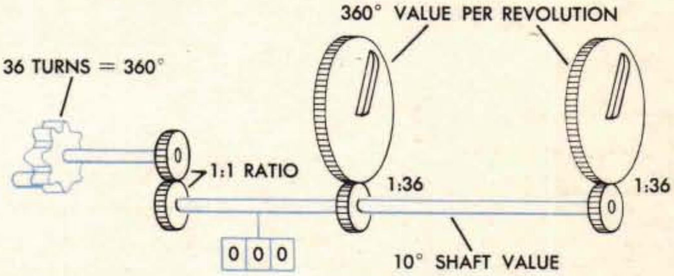
Using GEARS to MULTIPLY by a CONSTANT

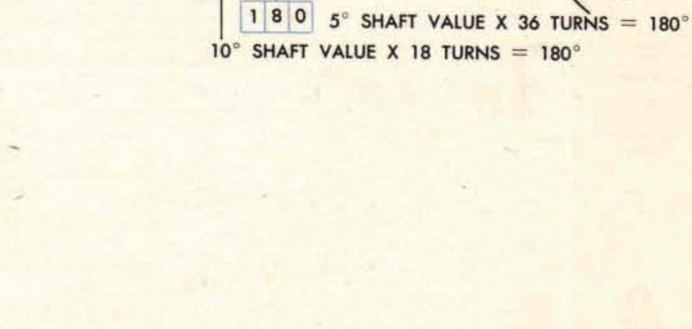
Here a handcrank and shaft line are used to position two large slotted vector gears in computing mechanisms.

The handcrank and the shaft have a shaft value or value per revolution of 10°. The shaft turns both vector gears through a 1 to 36 gear ratio. Thirty-six turns of the handcrank at 10° per revolution position the shaft line at 360° total value. The shaft value or value per revolution of both vector gears is also 360°.

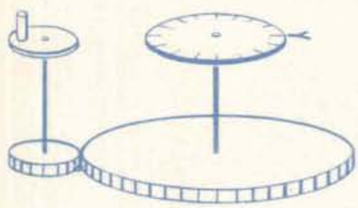
In solving a fire control equation mechanically it is sometimes necessary to have any given input turn one of these vector gears twice as far as the other. In this example, one vector gear will then turn *two* revolutions instead of one when the input shaft turns from 0° to 360° total value. If the vector gear turns two revolutions for 360° total value, the required value per gear revolution is 180°. To obtain this 180° value, a 2:1 gear mesh is introduced into the shaft line to multiply the shaft revolutions by two and so reduce the input shaft value to 5°. With this new gear ratio the 18 revolutions of the handcrank required to set in a value change of 180° will turn one vector gear one-half a revolution and the other vector gear one revolution.

By introducing gear meshes to change shaft value and so change the value per revolution of the mechanism input, any value may be multiplied by a constant. The constant is usually written K.



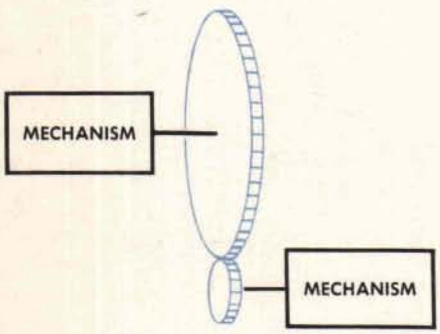


Using gears to change shaft values



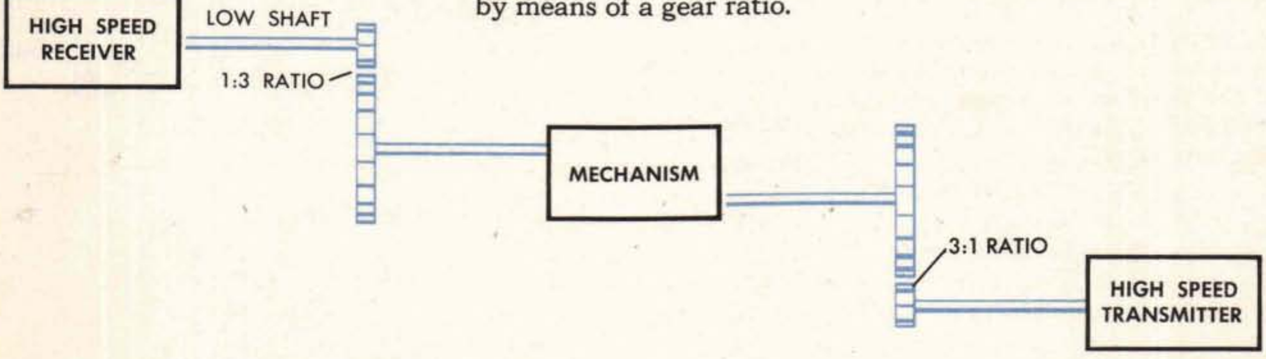
Gear ratios are often used for no other reason than to change the shaft values. If a shaft has a value of 500 yards per revolution, it is very often desirable to reduce this value to some other value, say 50 yards per revolution.

Suppose that a dial is to be positioned very accurately by means of a hand crank. Delicate motions of a hand crank are almost impossible under battle conditions. It is often desirable to use a gear ratio between the hand crank and the dial so that 10 or more revolutions of the hand crank will produce only one revolution of the dial.



Computing mechanisms invariably require different shaft values. One mechanism might be built, with the required accuracy, having an output of 5 revolutions equals 500 yards. To obtain the same accuracy with another computing device it might be necessary to make the shaft value 9 revolutions equals 500 yards. Rather than build all mechanisms to produce the same shaft values, which would make most mechanisms larger and produce a much bulkier computer, it is customary to use gear ratios to adjust the output of one mechanism to fit the input of the next.

Various electrical follow-up devices operate efficiently only at comparatively high speeds with low shaft values. When a signal is received by means of such a device, it is customary to reduce the speed and increase the shaft value of the signal received to the values of the mechanisms in the computer, by means of gear ratios. Similarily, when a high value signal is to be sent from the computer to the guns by means of a relatively low-shaft-value transmitter, the shaft value may be reduced by means of a gear ratio.



Using gears to reduce lost motion errors

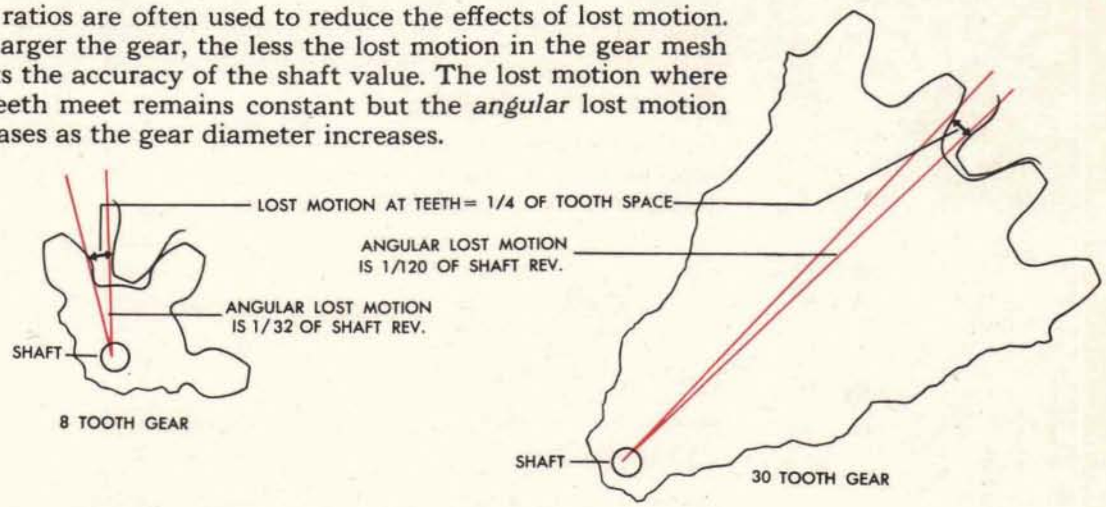
The total amount of value loss due to lost motion in a shaft line depends on:

1 The size of the gears used

2 The shaft value carried by the shafts in one revolution

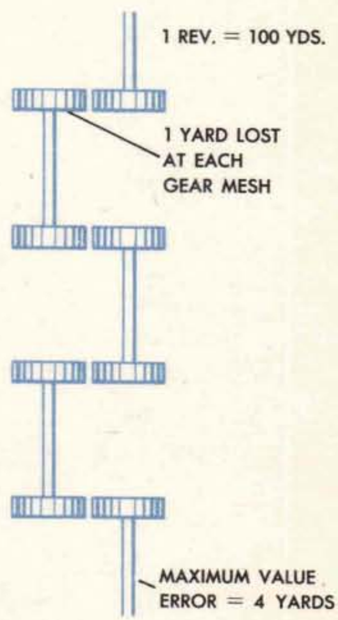
Larger gears reduce angular lost motion

Gear ratios are often used to reduce the effects of lost motion. The larger the gear, the less the lost motion in the gear mesh affects the accuracy of the shaft value. The lost motion where the teeth meet remains constant but the *angular* lost motion decreases as the gear diameter increases.



Because large driving gears have less angular lost motion in transmitting a signal mechanically from one mechanism in the computer to another, it is often advantageous to reduce the shaft value with a gear ratio and step it up again at the point of delivery.

How gear size and shaft value affect lost motion error



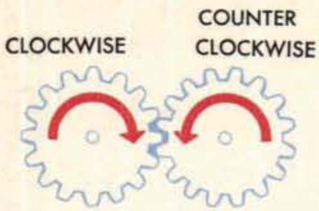
Assume that a shaft line has four 1:1 gear ratios and the value per revolution of each shaft is 100 yards. If the gears used are all of such a size that the angular lost motion at each mesh is one yard, the greatest value error due to angular lost in the shaft line will be 4 yards.

If the gears used were twice as large, the linear lost motion between the meshing teeth would remain about the same, but the *angular* lost motion would be half as great, thus cutting the value error in half, that is, to 2 yards.

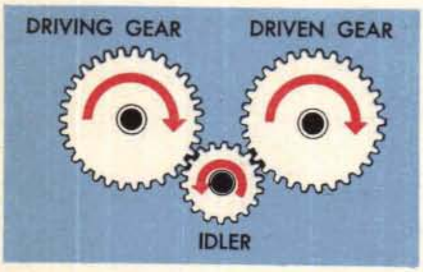
If the shaft value per revolution were only 50 yards instead of 100 yards, the maximum value error would also be cut in half.

It is important to understand that the maximum value error due to angular lost motion remains the same regardless of the number of shaft revolutions. As soon as the teeth on all the gears in a shaft line take up the lost motion by moving to their driving position, the maximum value error is reached and cannot increase during any additional turning in the same direction.

GEAR TRAINS

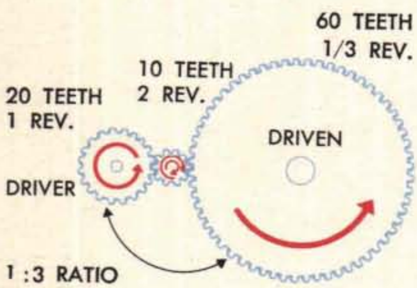


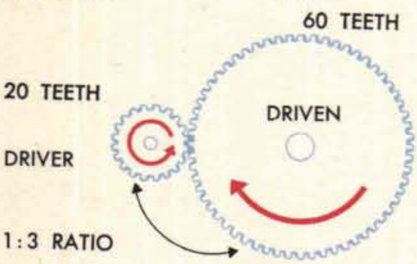
Any two mating spur gears turn in opposite directions.



If a shaft is required to turn another shaft in the *same* direction, an idler gear must be put between the driving gear and the driven gear. The idler will turn in the *opposite* direction to the driving gear, and will turn the driven gear in the *same* direction as the driving gear.

An idler between two gears does not affect the gear ratio, because each time the driving gear turns one tooth of the idler, the idler turns one tooth of the driven gear.





Here's an example:

Suppose a 20-tooth pinion is driving a 60-tooth gear through a 10-tooth idler.

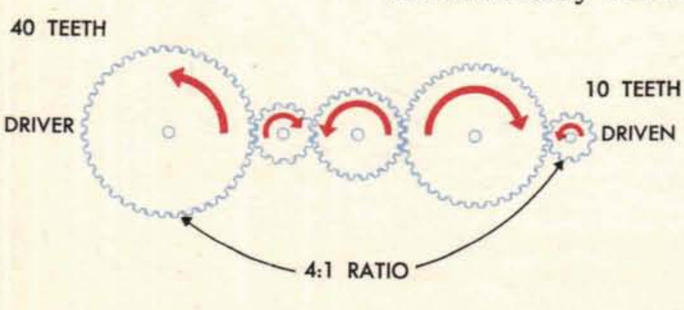
For each revolution of the driving pinion the idler will make 2 revolutions, because the idler has half as many teeth as the pinion.

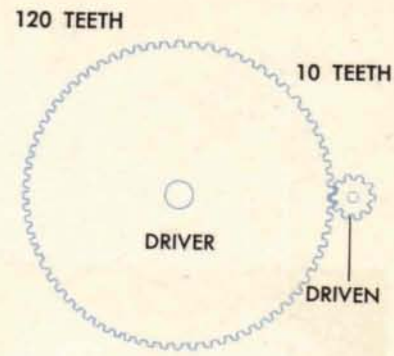
For each revolution of the idler, the driven gear will turn $1/6$ revolution, because the gear has 6 times as many teeth.

So for each revolution of the pinion, the idler makes 2 revolutions and the driven gear makes $2 \times 1/6 = 1/3$ revolutions.

The ratio is 1: 3, which is the same as if the pinion had driven the gear directly.

Thus when several gears are meshed together in this way, the ratio between the driving gear at one end and the driven gear at the other end is always the same as if the driving gear were meshed directly with the driven gear.



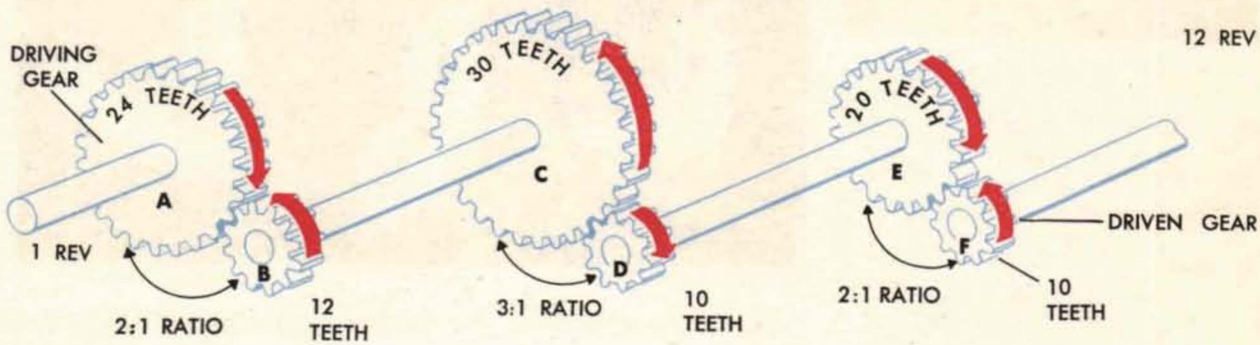


When a large increase in the number of revolutions is required, the increase can be made in several steps, using intermediate shafts, each of which carries two different size gears.

For example, suppose a 12 : 1 ratio is needed between two shafts.

To do this in one step would require the driving gear to be 12 times as big as its pinion, which would be very inconvenient and waste a lot of space.

It might be done this way:



Gears *A* and *B* have a 2 : 1 ratio. For each turn of the driver *A*, gear *B* makes 2 revolutions.

Since gears *B* and *C* are on the same shaft, gear *C* also turns twice for one turn of gear *A*.

Gears *C* and *D* have a 3 : 1 ratio. Gear *D* turns 3 revolutions for each turn of *C* or ($3 \times 2 =$) 6 revolutions for each turn of *A*.

Gear *E* is on the same shaft as gear *D; E* also turns 6 times for one turn of *A*.

Since *E* and *F* have a 2 : 1 ratio, *F* turns twice for each turn of *E*, or ($2 \times 6 =$) 12 times for each revolution of the driving gear *A*.

The ratio between *A* and *F* is, therefore, 12 : 1, and this ratio is achieved without the use of large gears.

To find the ratio of a train of this kind quickly, multiply together the ratios between each pair.
The ratio in this example is:

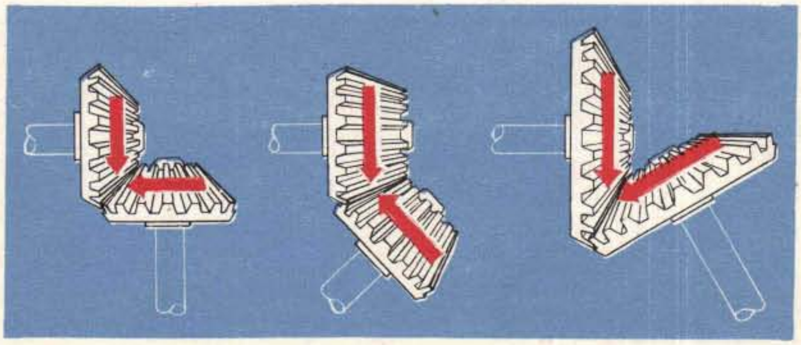
$$\frac{24}{12} \times \frac{30}{10} \times \frac{20}{10} = \frac{12}{1}$$

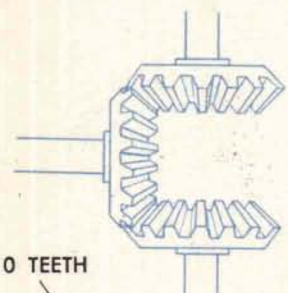
DIFFERENT TYPES of GEARS

So far only spur gears have been considered.

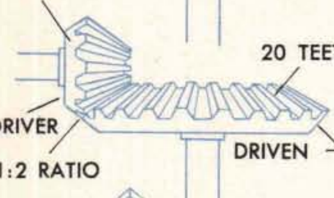
Spur gears will transmit motion only between parallel shafts. When shafts are not parallel *bevel gears* are usually used.

Bevel gears can transmit motion between shafts at almost any angle to one another because bevel gears can be designed to suit the angle between any two shafts.

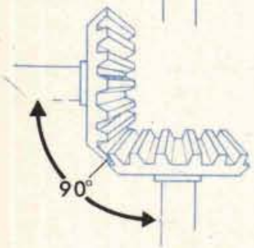




By using bevel gears several shafts at different angles can be driven by one driving shaft.



The gear ratios for bevels are found in the same way as for spur gears, by counting the teeth on each gear.



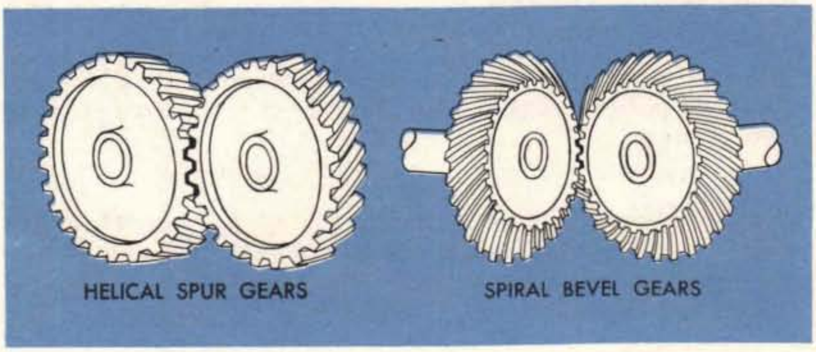
MITER GEARS 1:1 RATIO

If a pair of bevel gears are of equal size and their shafts are at right angles, they are called MITER gears.

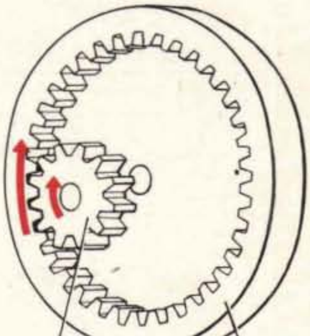
In SPIRAL GEARS, the teeth are cut slantwise across the face of the gear. One end of a tooth, therefore, lies ahead of the other. That is, each tooth has an "advanced end" and a "trailing end."

In straight tooth spur gears, the whole width of the face of the gear comes into contact at one time. But in spiral gears, contact between two teeth starts first at the advanced end of each tooth and moves progressively across the face of the gear until the trailing ends of the teeth are in contact.

Because of the slant cut of the teeth more than one tooth is in mesh at a time. This kind of meshing action keeps the gears smoothly in contact with one another, resulting in smoother and quieter operation.



INTERNAL GEARS are gears with their teeth cut on the inside of a ring and pointing inward toward the axis of rotation.



An internal gear must mesh with an external gear, whose center is offset from the center of the internal gear.

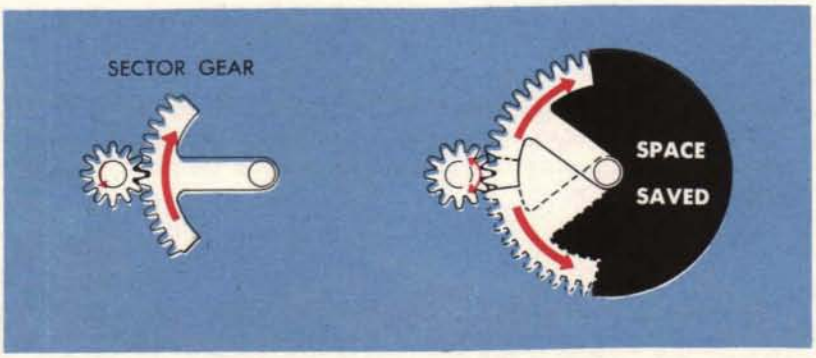
Either the external or the internal gear can be the driving gear. The gear ratio is the same as for external gears. It is:

$$\frac{\text{The number of teeth in the driving gear}}{\text{The number of teeth in the driven gear}}$$

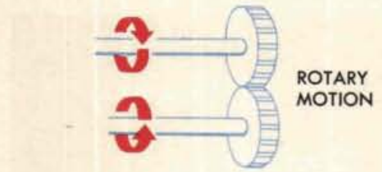
Sometimes only a part of a gear is needed, where the motion of the pinion is limited.

In a case like this a *sector gear* is used to save space.

A sector gear is simply part of a gear.



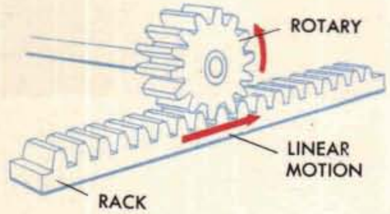
STRAIGHT and ROTARY motion



In fire control, values are transmitted by positions of shafts and parts of mechanisms. Some of these parts of mechanisms, such as racks, move in linear motion.

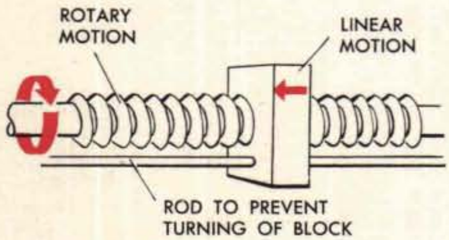
A rack is simply a straight bar with gear teeth cut on it.

When a gear positions another gear it is transmitting rotary motion.

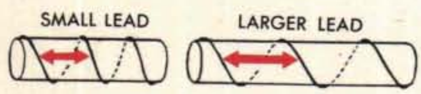


When a gear positions a rack it is converting rotary motion into linear motion. When the gear turns, the rack moves along its guide rails. The rack can also drive the gear. As the rack moves along, it turns the gear.

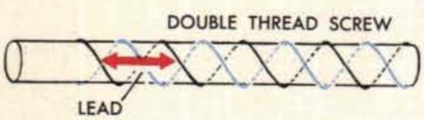
The rack transmits values by its position, just like shafts and gears. Its position is the *linear* distance it has moved from its zero position.



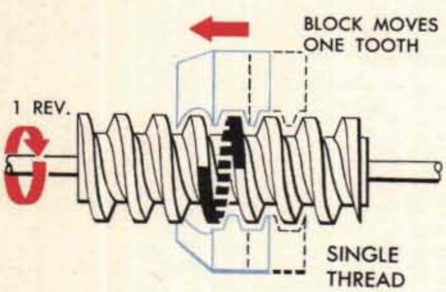
Another device which converts rotary motion to linear motion is the screw and traveling block, or nut. The block travels on the screw just as a nut moves along a bolt when the bolt is turned and the nut is held.



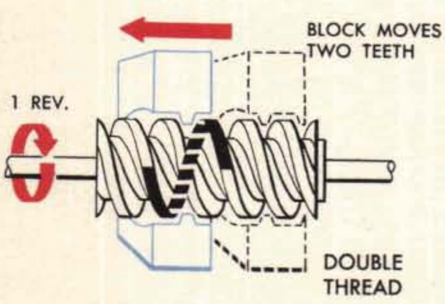
The distance the block travels for each turn of the screw depends on the "lead" of the screw thread. If a line is drawn along the screw parallel to the center line of the screw, the lead is the distance between the spirals of a thread, measured along this line.



Sometimes a screw has a second thread cut parallel to the first in order to get more contact surfaces between the screw and the follower. A screw with one thread is called a single-thread screw; a screw with two threads is called a double-thread screw.



FOR EACH TURN OF THE SCREW THE FOLLOWER BLOCK TRAVELS A DISTANCE EQUAL TO THE LEAD.



The distance the follower block travels for one turn of the screw is always equal to the lead, that is, the distance between corresponding points *on the same thread,* no matter how many threads there are.

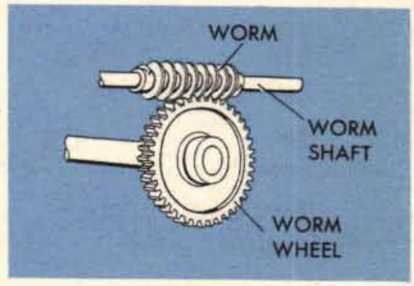
In a *single-thread* screw the lead is the width of *one* tooth.

In a *double-thread* screw the lead is the width of *two* teeth.

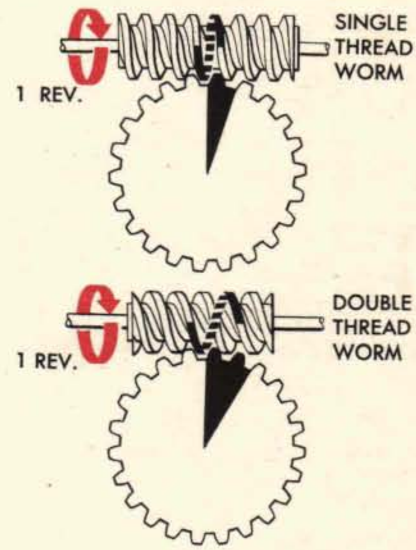
The WORM and the WORM WHEEL

A worm is a screw with a thread of special shape.

Instead of moving a block the worm drives a worm wheel.



A single-thread worm turns its worm wheel one tooth for each revolution of the worm.



The black sectors show how much the wheels will be turned by one revolution of the worms.

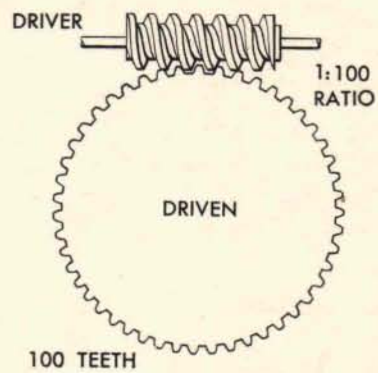
A double-thread worm turns its wheel two teeth for each turn of the worm.

Worms can also have three or four or more threads. The number of wheel teeth turned for each revolution of the worm is always the same as the number of threads on the worm.

Worms are often used where great reductions in amount of rotation are needed, because the ratio of rotation between the worm and its wheel is usually large.

Since each thread of the worm moves only one tooth of the wheel the gear ratio between worm and wheel is:

$$\frac{\text{The number of threads in the driving worm}}{\text{The number of teeth in the driven wheel.}}$$



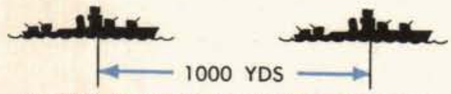
Here is a single-thread worm with a 100 tooth wheel. The worm must make 100 revolutions for one complete turn of the worm wheel.

The gear ratio is 1:100.

Sometimes the worm wheel drives the worm. This is possible only when the slope of the worm threads is greater than 5°.

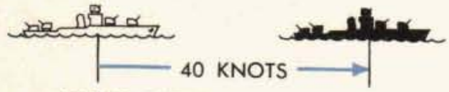
BASIC MATHEMATICS

Mastery of certain mathematical principles is a fundamental requirement for understanding fire control mechanisms. Many of these are well worth committing to memory:



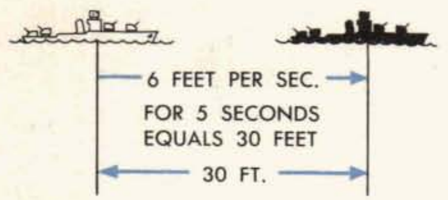
LINEAR MEASURE INDICATES DISTANCE

Linear measure is the *distance* between two fixed points measured in a straight line. In fire control, the units of measurement are usually yards and nautical miles.

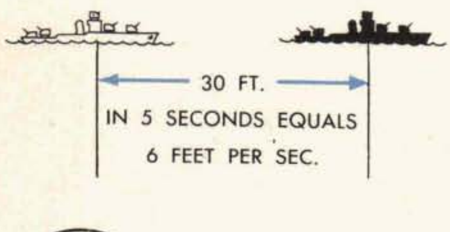


LINEAR RATES REPRESENT SPEED

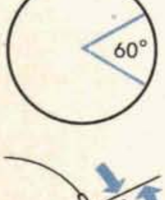
A *linear rate* is the *speed* of an object moving in a straight line. All linear rates tell the *distance* that an object will move in a given *time*. Linear rates are usually expressed in yards per second or in knots.



Multiplying a *linear rate* by the *time* that has elapsed during the movement of an object produces the *linear distance* traveled in that time. A ship traveling at a linear rate of 6 feet per second for a period of 5 seconds will move a distance of 30 feet.

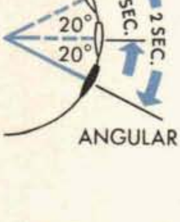


Dividing linear *distance* by the *time* required for an object to move that distance will produce the *linear rate*. A ship traveling 30 feet in 5 seconds moves at the rate of 6 feet per second.



ANGULAR MEASURE SHOWS THE SIZE OF AN ANGLE

Angular measure is the size of a given angle expressed in degrees, minutes, and seconds. Angles can also be expressed in *radians* as will be shown later.

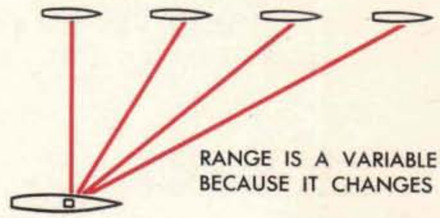


ANGULAR RATES SHOW THE SPEED WITH WHICH AN ANGLE VARIES

ANGULAR RATE= 20° PER SEC.

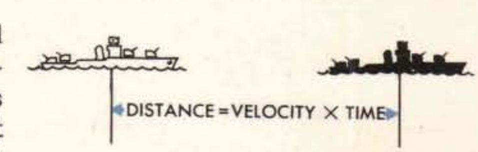
An *angular rate* is the speed with which an angle changes. Angular rates can be expressed in degrees per minute, or minutes per second, or *radians* per second.

A quantity that changes is called a *variable.* For example, the RANGE input to a computer is a variable because the range value is constantly changing as the position of the Target changes with relation to Own Ship.

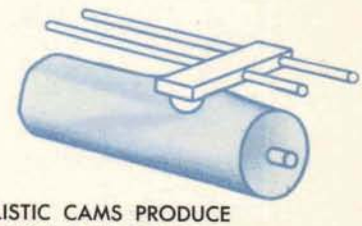


RANGE IS A VARIABLE BECAUSE IT CHANGES

A variable that derives its value from another variable is called a *function* of that variable. When the function increases or decreases uniformly as the variable increases, the function is called a *linear function.* If an object is moving at a constant velocity, the distance it travels is a linear function of the time of travel. Distance equals velocity times time.

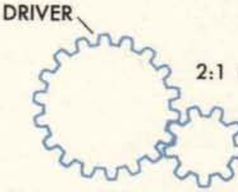


In fire control problems, an *empirical function* is one whose value in relation to a variable has been established by observation. Ballistic cams deliver empirical functions because the data cut into each cam is based on the observations of the flight of the projectile.



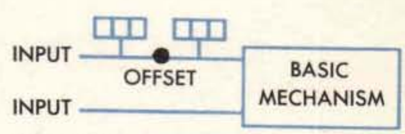
BALLISTIC CAMS PRODUCE EMPIRICAL FUNCTIONS

A *constant* is a quantity whose value does not change.



GEAR RATIOS PROVIDE A CONSTANT FOR MULTIPLICATION

A variable is often multiplied by a constant to produce an approximation of another variable. When a constant is *added to* or *subtracted from* a variable, it is called an *offset.*



AN OFFSET IS A CONSTANT TO BE ADDED OR SUBTRACTED

The *reciprocal* of a number is 1 divided by that number. The reciprocal of 5 is $1/5$. Multiplying by the *reciprocal* of a number is the same as *dividing* by that number. Division in mechanical computers is usually accomplished through multiplication by the reciprocal.

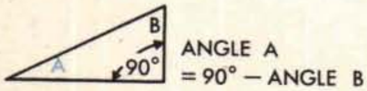
RECIPROCALS CAN BE COMPUTED BY A CAM

Right Triangles

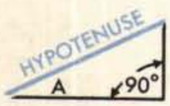
The sum of the angles in any plane triangle is always 180°.

A right triangle has one 90° angle; therefore 90° plus angle *A* plus angle $B = 180°$.

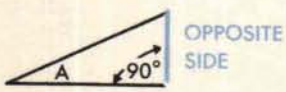
Angle A plus angle B will always equal 90° in any right triangle.



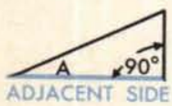
If angle *A* is known, angle *B* can be found because angle $B =$ 90° minus angle *A*.



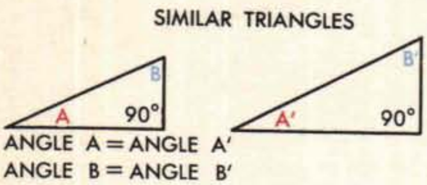
The side opposite the right angle is always the longest side and is called the *hypotenuse.*



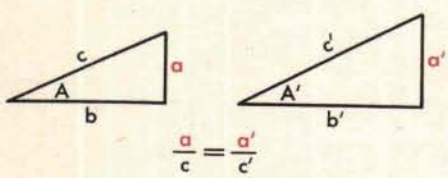
The side opposite angle *A* is called the *opposite side* to that angle.



Angle *A* is formed by the hypotenuse and one *side* of the triangle. This side is called the *adjacent side* to angle *A*.



Right triangles can have the same *angles* but be of different *sizes.* Triangles of different sizes but having the same angles are called *similar triangles.* In two similar triangles the ratio between any two sides of one triangle is equal to the ratio between the corresponding two sides of the other triangle.



As long as angle *A* remains the same, the *ratio* of any two sides of the triangle will be the same, regardless of the *size* of that triangle. Six ratios can be obtained by using the three sides. These ratios are called natural trigonometrical functions.

Trig functions

1 The opposite side divided by the hypotenuse is called the *Sine of A.* It is written *sin A.*

2 The adjacent side divided by the hypotenuse is called the *Cosine of A.* It is written *cos A.*

3 The opposite side divided by the adjacent side is called the *Tangent of A.* It is written *tan A.*

4 The adjacent side divided by the opposite side is called the *Cotangent of A*. It is written *cot A*.

5 The hypotenuse divided by the adjacent side is called the *Secant of A*. It is written *sec A*.

6 The hypotenuse divided by the opposite side is called the *Cosecant of A*. It is written *csc A*.

These are the six Natural Trigonometric Functions. If the value of any one of these functions is known, the value of the angle in degrees can be found in a table of Trigonometric Functions.

The cotangent and cosecant are seldom used in the mechanical solution of a fire control problem. The other four functions should be carefully memorized.

The first three functions, Sine, Cosine, and Tangent, are the most used functions. Knowing the first three functions the other three can be found.

$$\csc A = \frac{\text{hypotenuse}}{\text{opposite side}} \text{ and } \sin A = \frac{\text{opposite side}}{\text{hypotenuse}}$$

If the terms in the sin A equation are inverted:

$$\frac{1}{\sin A} = \frac{\text{hypotenuse}}{\text{opposite side}}$$

Then: $\csc A = \dfrac{1}{\sin A} \quad \sec A = \dfrac{1}{\cos A} \quad \cot A = \dfrac{1}{\tan A}$

Measuring the sides of the right triangle

If one side of a right triangle and angle A are known, the other two sides may be found by using the trig functions of angle A.

Knowing that $\dfrac{\text{opposite side}}{\text{hypotenuse}} = \sin A$, to solve for the opposite side, multiply both sides of this equation by the *hypotenuse:*

$$\text{opposite side} = \text{hypotenuse} \times \sin A.$$

In the same way, the other equations can be changed to give:

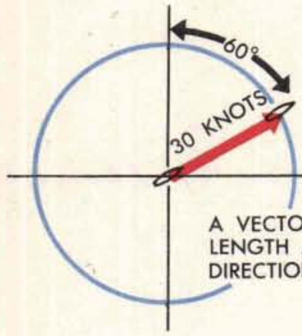
$$\text{opposite side} = \text{adjacent side} \times \tan A$$

$$\text{adjacent side} = \text{hypotenuse} \times \cos A$$

$$\text{adjacent side} = \frac{\text{opposite side}}{\tan A}$$

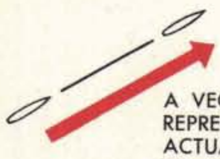
$$\text{hypotenuse} = \frac{\text{adjacent side}}{\cos A}$$

$$\text{hypotenuse} = \frac{\text{opposite side}}{\sin A}$$



VECTORS

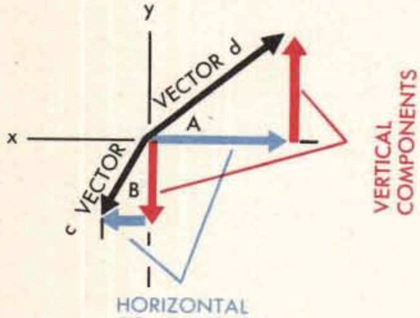
A *vector*, as used in a fire control problem, is a straight line with a definite *length* and *direction* which may represent either a *linear rate* or a *linear distance*.



To add or subtract vectors with *different* directions, it is necessary to break them up into *components*, with reference to a common axis, and add or subtract the corresponding components.

Suppose that two vectors with different directions are drawn from a common point. Their components from the point in a horizontal and vertical direction can be found by solving the two right triangles formed.

The y components are d sin A and c cos B
The x components are d cos A and c sin B



Solving an equation

An algebraic equation may be solved or simplified by adding the same value or subtracting the same value from both sides of the equation, or by multiplying or dividing both sides of the equation by the same value.

In the equation $ay = bx$, x can be found by dividing both sides of the equation by b.

$$\frac{ay}{b} = \frac{bx}{b} \text{ or, } x = \frac{ay}{b}$$

In the same equation, y may be found by dividing the original equation by a.

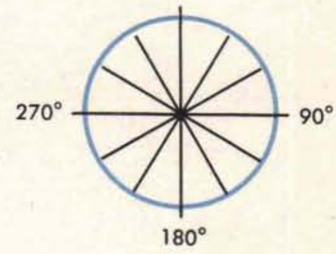
$$\frac{ay}{a} = \frac{bx}{a} \text{ or, } y = \frac{bx}{a}$$

If the equation read $y = \frac{bx}{a}$, the value of x could be found by multiplying both sides of the equation by $\frac{a}{b}$.

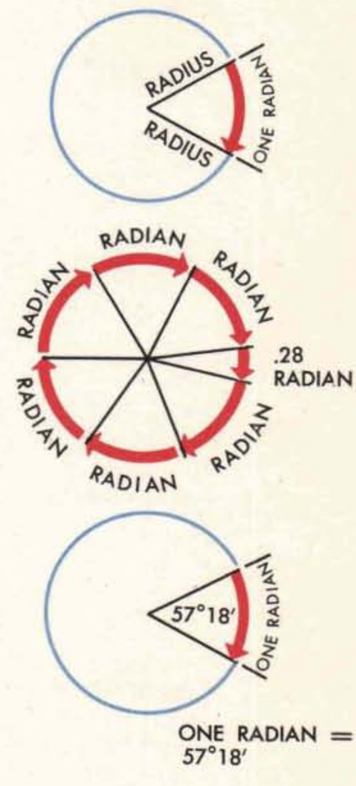
$$\frac{ay}{b} = \frac{abx}{ab} \text{ or, } x = \frac{ay}{b}$$

The values of a or b may be derived in the same manner.

RADIANS



The usual way to measure an angle is in degrees and minutes. The circumference of a circle is divided into 360 equal parts, or degrees. Each degree is further divided into 60 minutes.



Another extremely useful system of measuring angles is called *radian measure.*

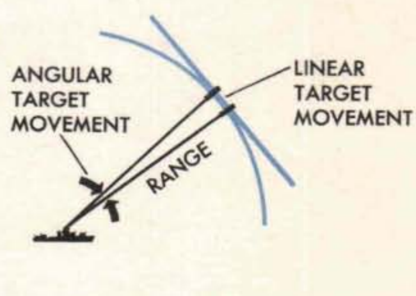
In radian measure, an arc equal in length to a radius of a circle is measured on the circumference of that circle. When two radii are drawn to the ends of this arc, the angle they measure is called a radian. A circle contains *6.28 radians.*

A circle contains 6.28 radians because the circumference of any circle equals 2π times the radius. As π equals 3.14 (approx.) then 2π equals 6.28. Since one radius measures one radian on the circumference there are always 2π or 6.28 radians in a circle.

Angles expressed in radians can be translated to angles expressed in degrees if it is remembered that 2π radians equal 360°.

$$\text{One radian} = \frac{360^\circ}{6.28} \text{ or } 57^\circ\ 18'$$

The chief importance of the radian measure in fire control is that the radian can be used to translate two linear measurements, such as target movement and range, into an angular measurement. If the target movement in a given period of time is known, and the range is known, the angular movement of the target can be expressed as a fraction of the range. Considering the range to be a radius, the fraction obtained will be the angular target movement in radians.



It should be borne in mind, however, that the radian is a *curved* unit, whereas the linear movement of a target is in a *straight* line. For the purposes of computation it is within the limits of accuracy to assume that the straight line and the curved arc of the radian are equal in length when the straight line measures a small angle.

BASIC SETTING INFORMATION

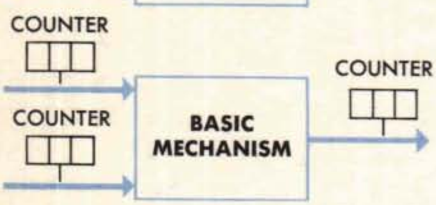
Each basic mechanism solves *a part* of the fire-control problem. It does not work alone, but is joined by shafts into a *network* of mechanisms. The *output* shaft from one mechanism is usually the *input* to another mechanism.

Naturally there must be coordination between all these parts. The problem of setting includes the setting of each individual mechanism and the joining of these mechanisms in their proper relationship.

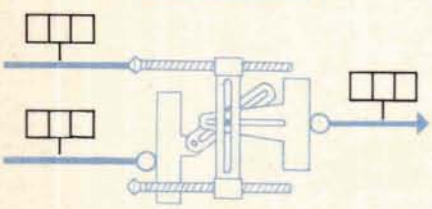
Each chapter in this pamphlet contains general setting instructions for the basic mechanisms covered in that chapter.

These setting notes in each chapter are not intended for making actual settings. They show only how *the parts of the various mechanisms are set.* Basic mechanisms used in more than one Ford Computer are covered in these notes. For this reason the setting procedures have been kept general. Specific setting instructions for each computer and its mechanisms are covered in each computer's setting notes.

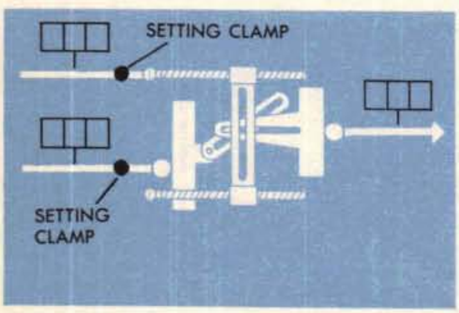
Every computer has the necessary dials and counters to show the positions of the mechanisms. However, every shaft in the computer *could* have its *own* dial or counter to show the value of the quantity on the shaft.



In these setting notes it will be *assumed* that there is a counter on the input and output shafts of each mechanism.



For instance, on a multiplier the shaft positioning the lead screw input will be shown with an attached counter, also the shaft which positions the input rack will have a counter, and the shaft positioned by the output rack will have a counter.



In all these mechanisms the setting clamp is placed between the imaginary counter and the input of the mechanism. The counter indicates the value on the shaft. Setting the mechanism to this counter automatically sets it to whatever value positions the shaft.

Here are a few things to remember in reading these setting instructions:

1 All setting clamps are loose before adjustment. They are tightened when the setting is completed.

2 Many mechanisms are set by positioning one input at zero, and then moving the other input while watching the output for zero or minimum motion. Take a multiplier for example: Any number multiplied by zero equals zero, so if one input to the multiplier is put at its zero position, movement of the other input should produce *no* movement of the output.

In general, this is the setting procedure:

a. One input line to the mechanism is put at its zero position.

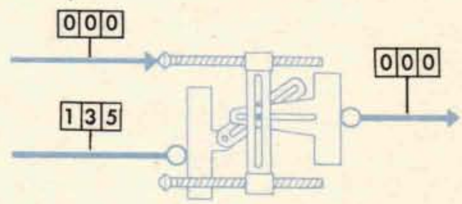
b. The corresponding input of the mechanism which is to be joined or "set" to the input line, is put at its estimated zero position.

c. The setting clamp is partly tightened—"slip-tightened."

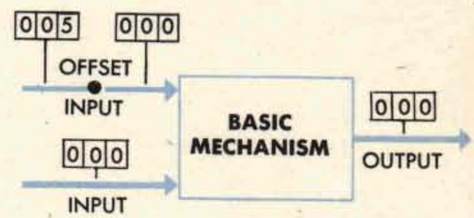
d. The other input of the mechanism is then moved.

e. If there is motion of the output, the setting is corrected through the setting clamp until the output motion is reduced to zero or to a minimum.

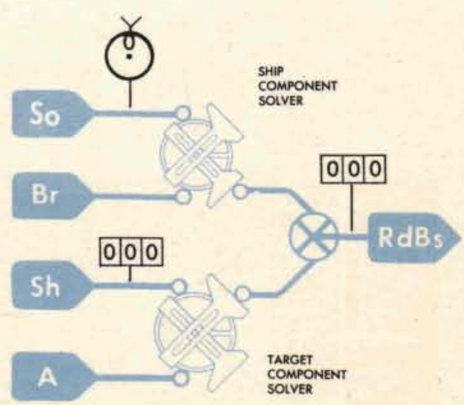
f. The other input usually can be set in the same way.



3 Usually, when an input to a mechanism is at its zero position, its counter is at zero. Sometimes this is not true, for example, when a constant offset is required. In this case, the zero position of the mechanism will be indicated on the counter by a reading equal to zero, plus the offset value. Each computer's setting notes give the offset values for the individual mechanisms.



4 For some of the mechanisms in the computers several input settings may be required to put one shaft in the zero position—for example, *RdBs* equals zero when both the *So* dial and the *Sh* counter read zero.



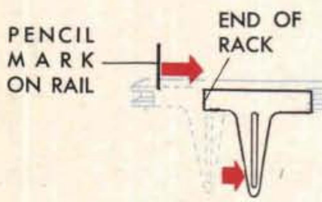
5 A computer's setting notes are more specific than these general setting notes, and should be used for all actual settings.

Here and there in the setting notes are instructions like "Observe the motion of the indicator," "Push the cam," or "Wedge the input." It will be a good idea to find out how to do these things now.

How to use the INDICATORS

Most mechanisms are set by observing the *motion of an output.* In these general setting notes *counters* are the only indicators used. However, there are several other devices which make good motion indicators.

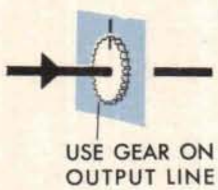
1 A dial may be substituted for a counter.



2 A rack may be used as an indicator by marking both the rack and its rail. Then the distance the rack moves from the mark can be measured.

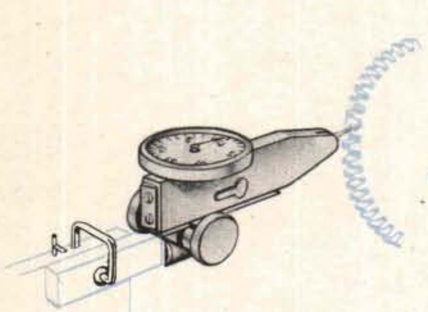
3 A gear may be marked with a pencil and read against a stationary mark made on the computer frame.

Here, too, the distance the gear moves from the mark can be measured.



4 The output gear on a follow-up makes an excellent indicator if the follow-up input is the value to be measured. When used to set for minimum motion, the follow-up output gear or shaft is marked with a pencil so that any motion can be detected and measured.

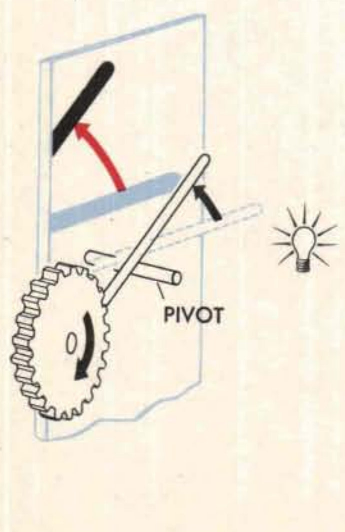
5 A dial indicator of the universal type illustrated provides an accurate means of measuring movement when setting to obtain minimum motion.



It is attached to a rack or gear in this way. Movement of the rack or gear is amplified many times in the indicator and moves a hand around a dial.

6 Another accurate way of amplifying small motions is to use a "shadow stick."

A shadow stick is a light lever which magnifies the motion of a gear or rack when a light casts the shadow of the lever on a surface behind it. The pivot may be a convenient shaft or surface in the mechanism.

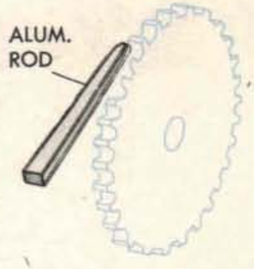


This is how it is used: Mark the position of the shadow before the rack or gear moves, and *after,* to see how far it has moved.

To get the best results the distance from the pivot to the rack or gear should be short and the light should be close to the stick.

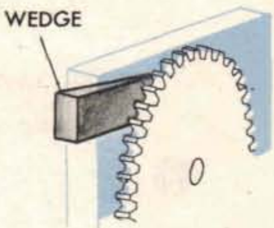
The factors governing the selection of the type of indicator to be used are *accessibility* and *sensitivity.* It is not necessary to use a sensitive dial indicator on a rough setting—it just makes the setting more difficult.

How to push a CAM or GEAR



The best way to slip a cam or gear which cannot be turned by hand is to put an aluminum rod against the base of one tooth and push firmly but gently in the proper direction to change its position. *Never use a hard metal pusher...* Steel rods and screw drivers should never be used for this purpose.

WEDGING an input



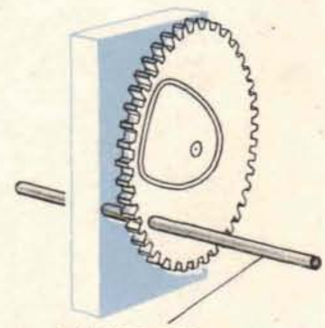
To hold an input shaft in one position, insert a bakelite or wooden wedge between the gear and the computer frame so that it keeps the gear and shaft from turning. To avoid damaging the shaft assemblies, a wedge should be inserted just firmly enough to hold the shaft line, but should not be hammered in.

When a setting has been completed, remember to remove all the wedges.

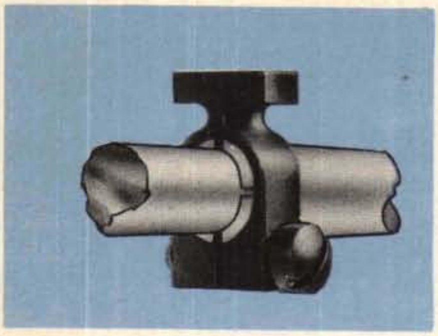
To ENERGIZE

When power is needed, the setting instructions say "Energize ...." This means to complete a circuit by connecting the proper leads to the power supply.

How to use a SETTING ROD



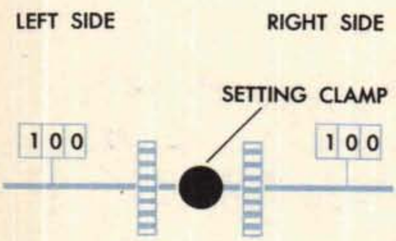
A setting rod is an accurately ground steel rod. There are usually two accurately sized holes provided in the parts to receive the setting rod... One hole is in the mechanism to be set and the other is in the computer frame. The Computer's setting notes give the values at which counters should be set when the setting rod is inserted through both holes.



CLAMPS

Clamps are mechanical "knots." They are used to tie inputs and mechanisms together, and to join the mechanisms of a computer into a network. Because clamps are *adjustable,* they can join these mechanisms in their proper relationship.

Setting clamps are placed in a computer so that they control the inputs to a mechanism or a series of mechanisms. Whereever possible, they are placed where they are easy to reach and easy to see. *Any clamp* in a computer, whether a setting clamp or an assembly clamp, can be used for setting. If any clamp becomes loose, it disturbs the network.

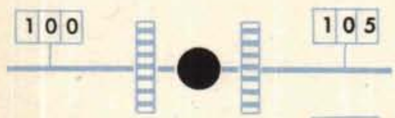


Here is a simple setting.

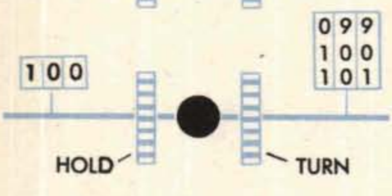
The clamp controls the relationship between the right and left sides. The counters indicate the value on each side of the clamp.

Most of the time the values have to be made equal. Here this is shown by a similar reading on both the counters.

When the counters are in agreement and the clamp has been tightened, the setting is complete.



Here the two sides of the clamp disagree. . . . Tightening the clamp now would make the right side in error by the amount of 5.



The error can be corrected by holding the left side and moving the right until the counter readings match.

Now tightening the clamp completes the setting.

Sometimes the sides should not be equal. A constant offset, *K,* can be added or subtracted by a clamp. Tightening the clamp when one side differs from the other by the constant *K* completes the setting. Here the constant is 20.

"Slipping through the clamp," means changing the relationship between two mechanisms controlled by the clamp, by holding one and turning the other.

"Slip-tighten the clamp," means to make the clamp tight enough to drive, but loose enough to allow "slipping through the clamp."

SECTION 2

MECHANICAL UNITS

The mechanisms in this book divide roughly into two groups:

a. those which are *purely mechanical,* and

b. those which are partly mechanical and partly electrical—*"electromechanical."*

Section 2 describes the mechanisms which are purely mechanical.

Within this strictly mechanical section the mechanisms divide into two groups:

a. those which do some type of mathematical computation, such as addition, multiplication, or trigonometric—the *computing mechanisms,* and

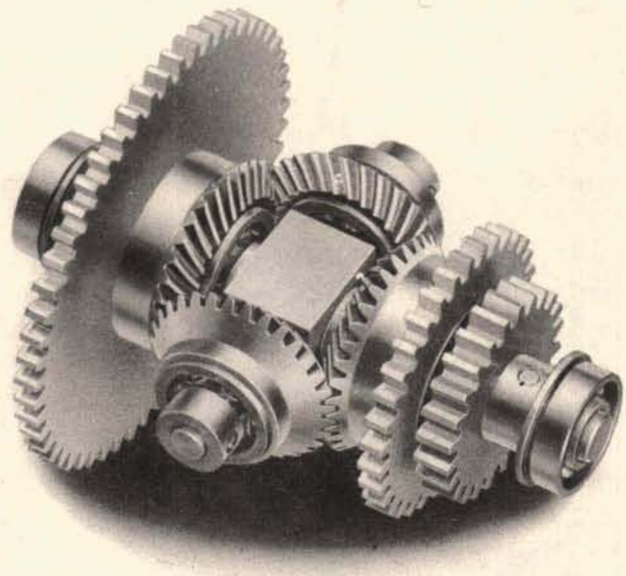
b. those that do not compute, but do other useful things—the *non-computing mechanisms.*

The computing mechanisms are covered first. They are arranged roughly in the order of increasing complexity, beginning with the relatively simple bevel gear differential and concluding with the component integrator. The non-computing mechanisms are grouped together in the concluding chapter of this section.

DIFFERENTIALS

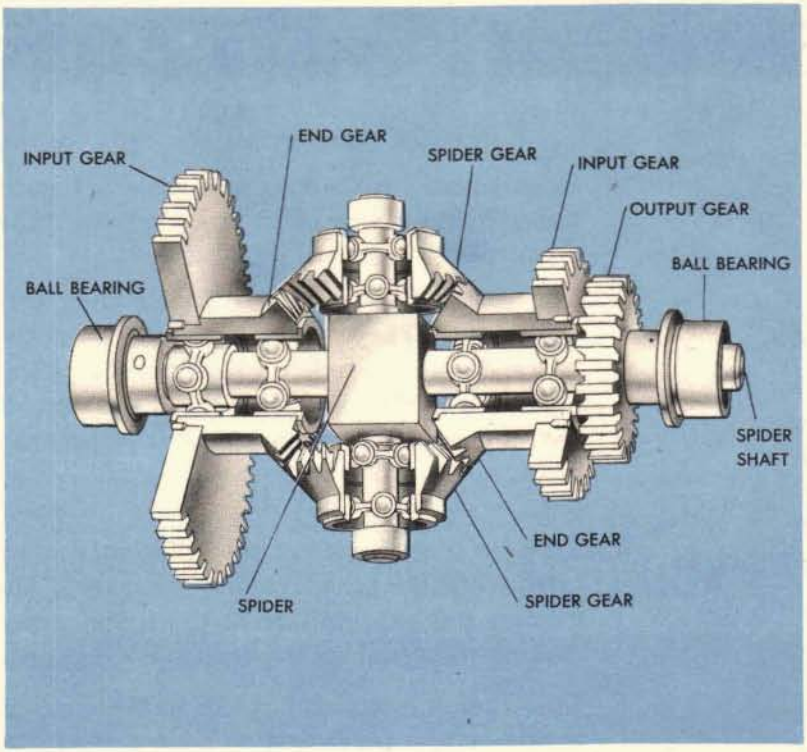
A differential is a mechanism that does addition and subtraction. To put it more precisely, it *adds* the total revolutions of two shafts—or *subtracts* the total revolutions of one shaft from the total revolutions of another shaft—and delivers the answer by positioning a third shaft.

A differential will add or subtract any number of revolutions, or very small fractions of single revolutions, continuously and accurately. It produces a continuous series of answers as the inputs change.

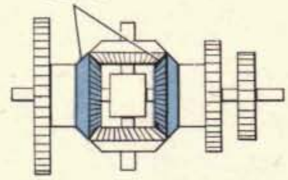


This is the symbol used to indicate the differential in schematic drawings. The cross in the center represents the spider. The arrows pointing inward represents inputs. The arrow pointing outward is the output. There are always two inputs and one output.

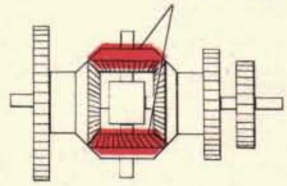
NOTE: In the illustrations which follow, the spider of the differential is assumed always to be the output. Actually the spider can be one of the two inputs.



The bevel gear differential

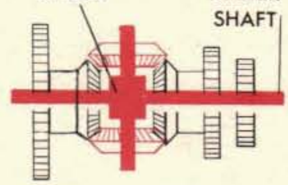


Above is a "cut away" drawing of a bevel gear differential showing all its parts and how they are related to each other. Grouped around the center of the mechanism are four bevel gears, meshed together. These four gears and the spider shaft are the heart of the differential.



The two bevel gears on either side are "end gears." The two bevel gears above and below are called "spider gears." The spider gears are meshed with the end gears.

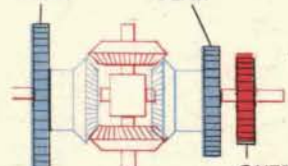
The cross shaft and spider gears taken together are called the "spider" and the long shaft is called the "spider shaft." All four of the bevel gears are free to rotate on precision bearings.



The three spur gears in the illustration are used to connect the two end gears and the spider shaft to other mechanisms. They may be any convenient size.

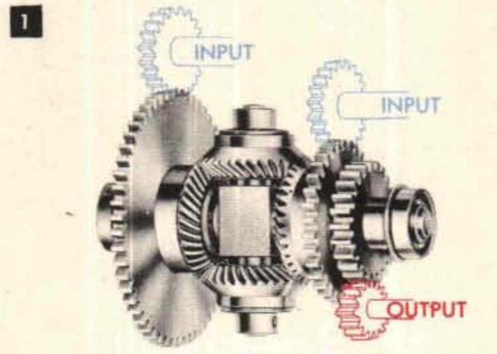
Each of the two input gears is attached to an end gear. An input gear and an end gear together are called a "side" of the differential.

The output gear is pinned to the spider shaft. It is the only gear in the mechanism that is pinned directly to a shaft.



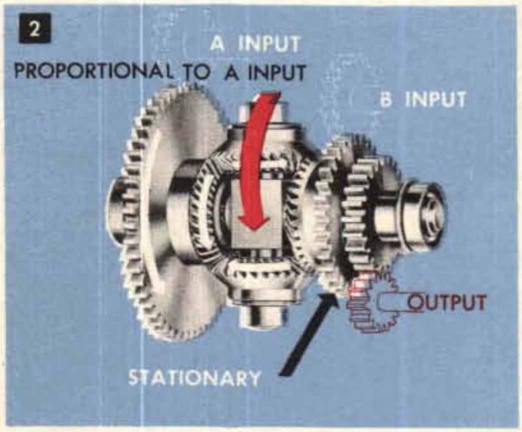
For the present it is assumed that the two sides are the inputs and the gear on the spider shaft is the output. Later it will be shown that any of these three gears can be either an input or an output.

How the SPIDER GEARS



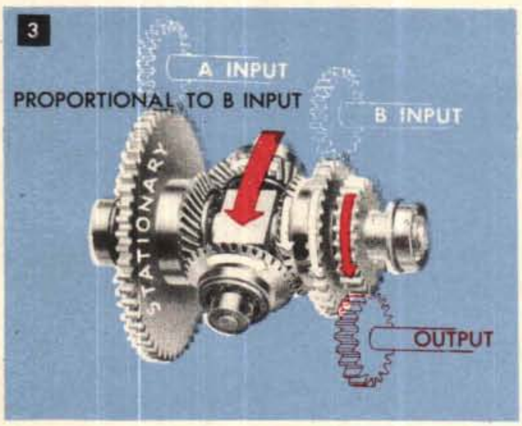
1 In this hook-up the two end gears are positioned by the input shafts, which represent the quantities to be added or subtracted.

The spider gears do the actual adding and subtracting. They follow the rotation of the two end gears, turning the spider shaft a number of revolutions proportional to the sum, or the difference, of the revolutions of the end gears.

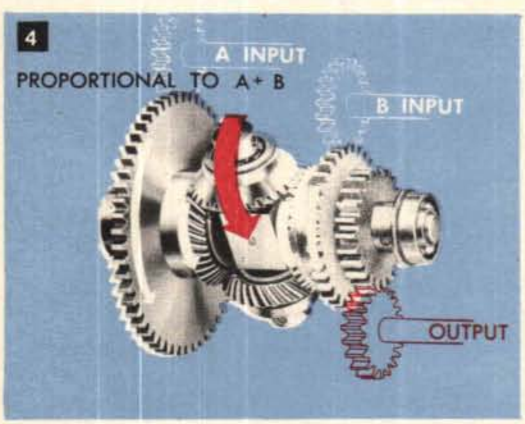


2 Suppose the left side of the differential is rotated while the other remains stationary. The moving end gear will drive the spider gears, making them roll on the stationary end gear.

This motion rotates the spider in the same direction as the input and, of course, turns the output shaft with it. The output shaft will turn a number of revolutions proportional to the input.



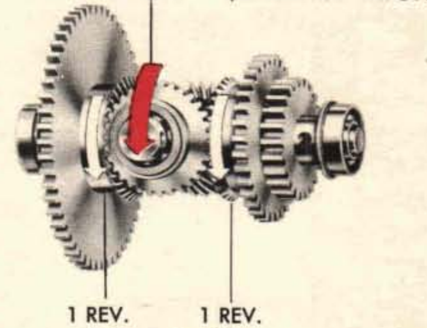
3 If the right side is now rotated and the left side held stationary, exactly the same thing will happen. The spider gears will again turn and roll on the stationary end gear, turning the spider in the direction of the moving side. The output shaft will turn a number of revolutions proportional to the input.



4 From these two examples it is easy to see that if *both* sides of the differential are turned in the same direction AT THE SAME TIME, the spider will be turned by *both at once*.

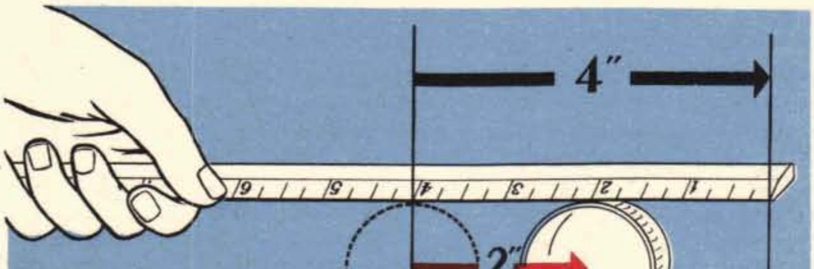
The output will be proportional to the *sum* of the two inputs.

work . . .



But the spider output will not be the whole sum of the two inputs. Actually, the spider makes ONLY HALF as many revolutions as the sum (or the difference) of the revolutions of the end gears. This is because the spider gears are free to *roll* between the end gears.

To understand this easily, imagine that a cylindrical drinking glass is being rolled along a table top by pushing a ruler across its upper side. The glass will roll only HALF as far as the ruler travels. The spider gears in the differential roll against the end gears in exactly the same way.

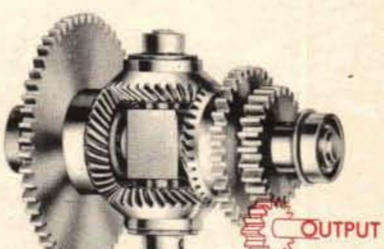


AS A MATTER OF FACT, THEN, A DIFFERENTIAL PRODUCES ONLY HALF THE ANSWER IN ADDING OR SUBTRACTING THE REVOLUTIONS OF ITS INPUT GEARS.

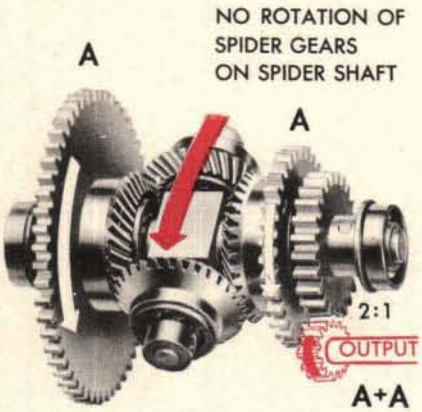
In order to produce the correct answer, 2:1 ratio gears would be needed between the spider shaft and the input shaft of the next mechanism in line.

Actually, the 2:1 ratio is seldom found in differential gearing in any computer for reasons of design.

For the sake of clarity, it is assumed here that all differentials have 2:1 gearing and that the final output is complete and correct.

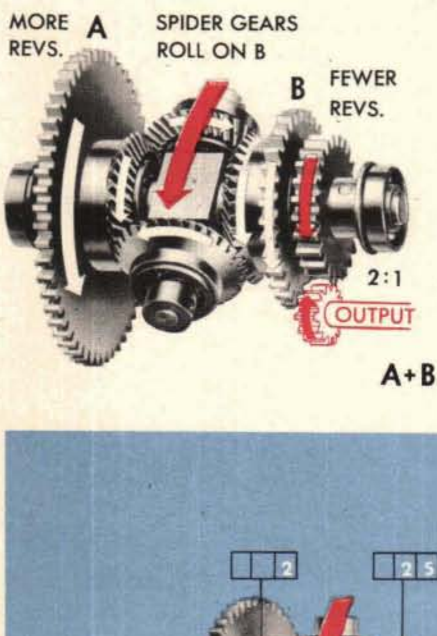


How the differential ADDS

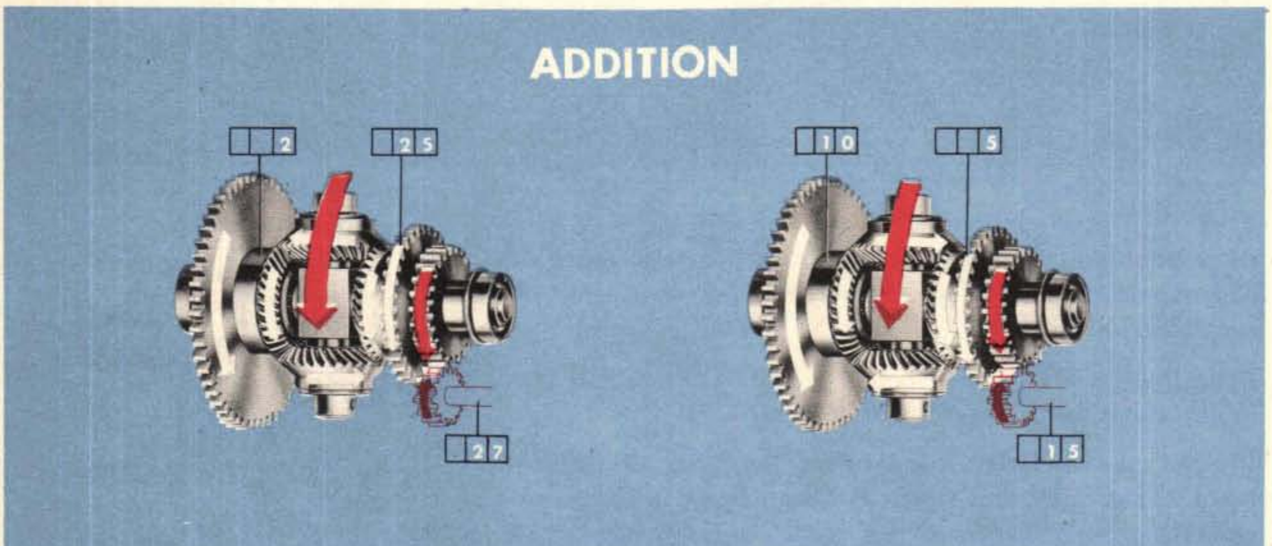


When both inputs of a differential rotate in the same direction, the differential *adds.*

If both sides of the differential turn in the same direction for the same number of revolutions, the spider gears do not rotate on the cross shaft. Instead they maintain a fixed position between the end gears and rotate with them, carrying the spider around to a new position. The rotations of the spider shaft are equal to half the sum of the revolutions of the two inputs.



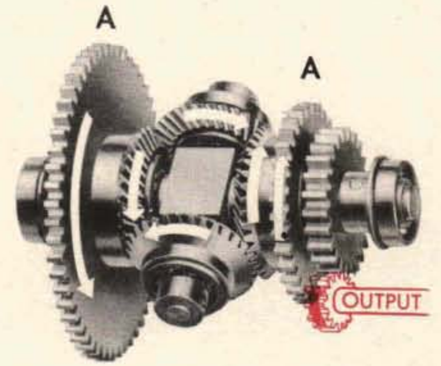
If one side of the differential makes more revolutions than the other, the spider gears will be carried around by both end gears. At the same time, the spider gears will roll on the end gear that is making the lesser number of revolutions. The spider shaft will be so positioned that it makes half the sum of the revolutions of the two inputs.



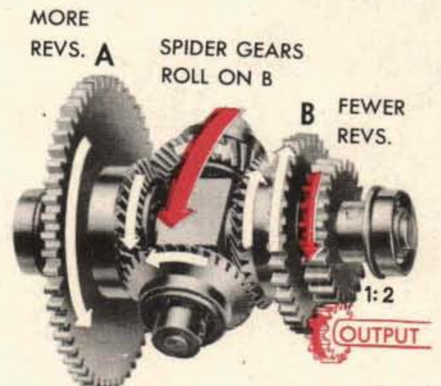
and SUBTRACTS

When the two inputs of a differential rotate in *opposite* directions, the differential *subtracts.*

If the two inputs turn in opposite directions for the same number of revolutions, the spider gears roll between the end gears without moving the spider at all. The output is zero. If the two inputs turn in opposite directions for an unequal number of revolutions, the spider gears roll on the end gear that makes the lesser number of revolutions, rotating the spider in the direction of the input making the greater number of revolutions. The motion of the spider shaft is equal to half the *difference* between the revolutions of the two inputs.

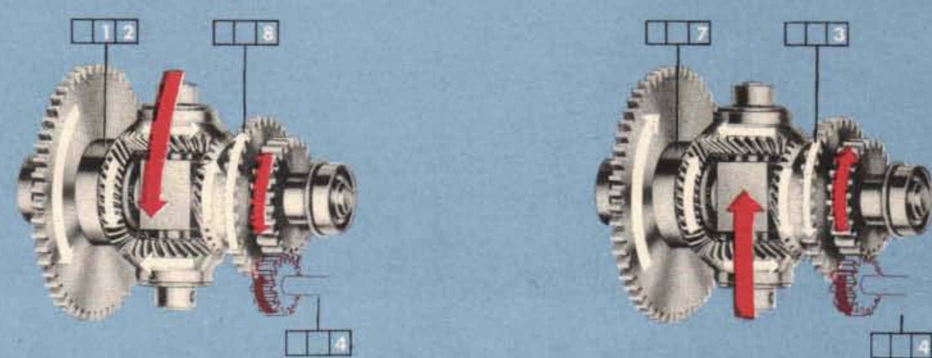


A–A = O



A – B

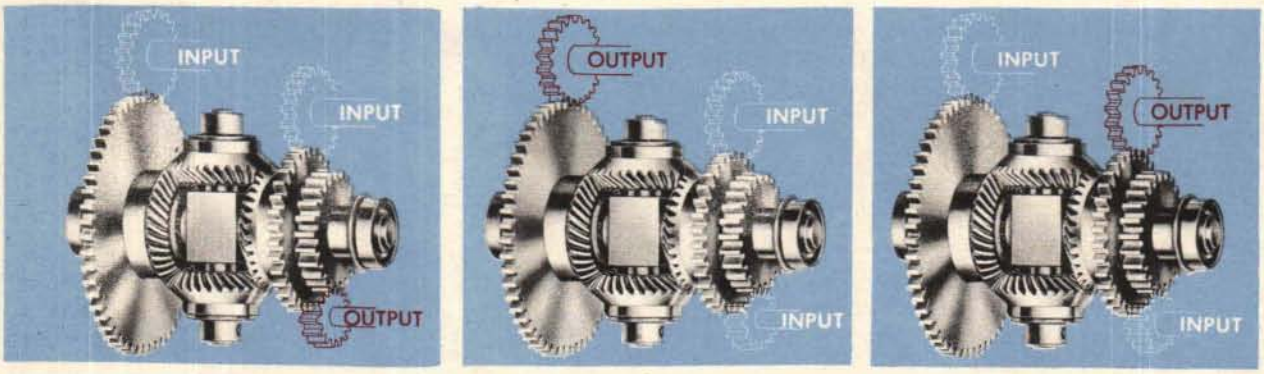
SUBTRACTION

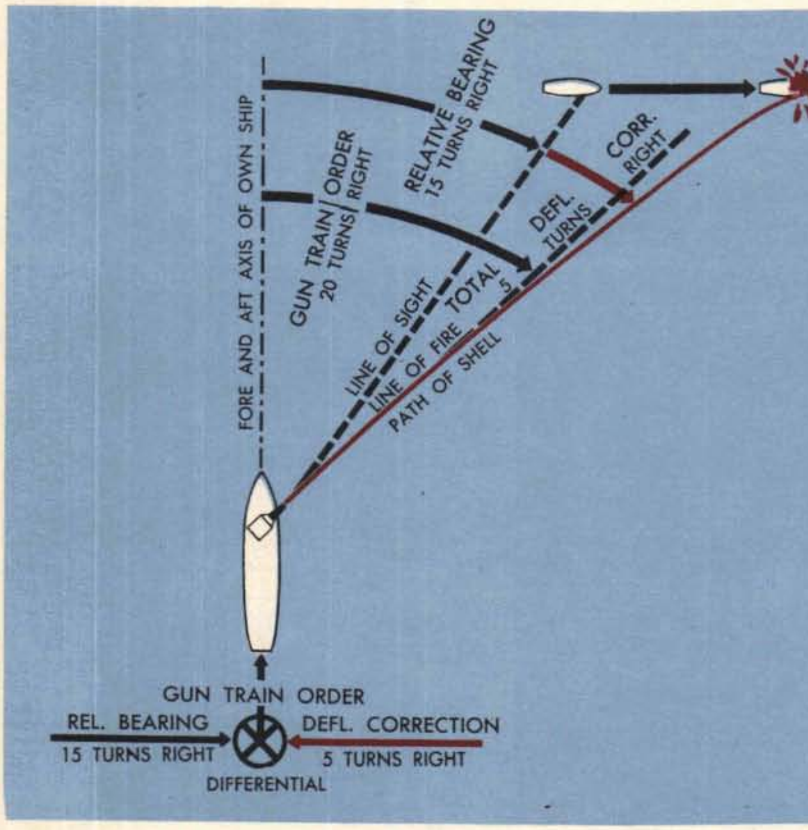


Various differential hook ups

As long as it is recognized that the spider follows the end gears for half the sum or difference of their revolutions, it is not necessary to use the side gears as inputs and the gear on the spider shaft as an output. The spider shaft may be used as one of the inputs and either of the sides used as the other input. In this case the second side becomes the output.

This fact permits three different hook-ups for any given differential. In computers any of the three hook-ups may be used, depending upon which proves most convenient mechanically.





Here is the kind of arithmetic problem that the differential solves. The total deflection correction is being added to relative bearing to produce gun order.

Few gunnery problems are, of course, as simple as this one. In a modern fire control system, differentials are invariably used in combination with other mechanisms to aid in the solution of a highly complex problem. A single computer may contain as many as 200 differentials.

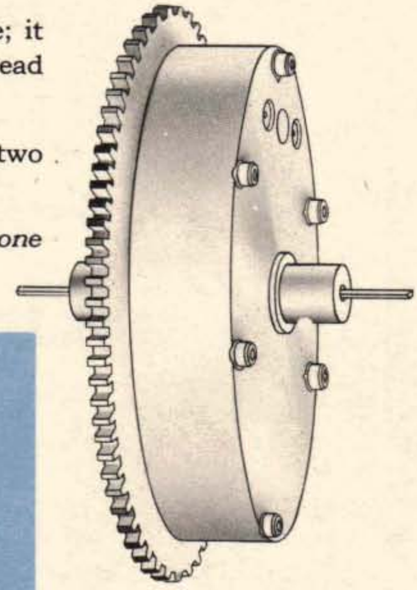
The JEWEL differential

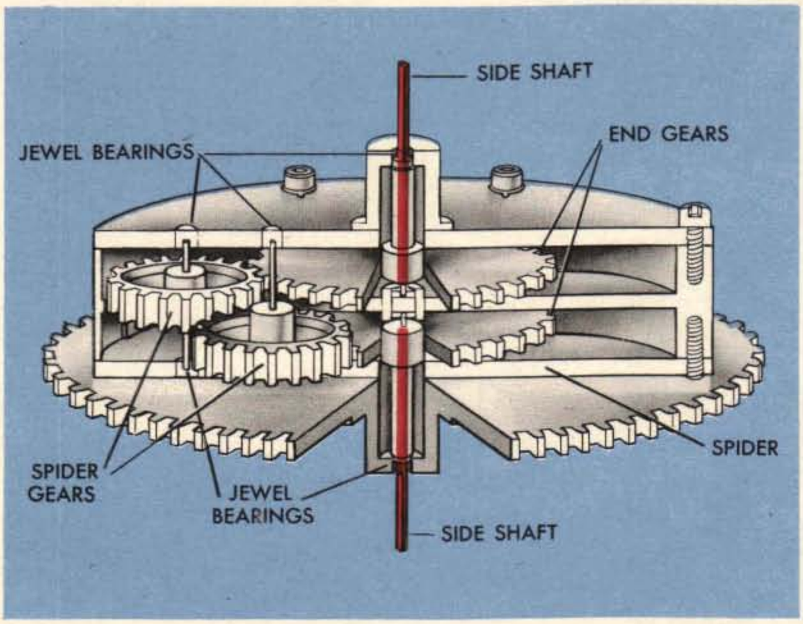
A differential can be made of spur gears instead of bevel gears. The jewel differential is an example.

The jewel differential works just like the bevel gear type; it differs only in construction and in the use of spur gears, instead of bevel gears.

The spider of the differential is a case which encloses the two end gears and the two spider gears.

The two spider gears mesh together, and each meshes with *one* of the end gears.





The shafts of the spider gears turn on jewel bearings set into the spider, so that the spider gears travel around with the spider just as in the bevel gear differential.

Each side of the jewel differential consists of a spur end gear and a side shaft.

In the jewel differential most of the shafts run on jewel bearings so that the mechanism is sensitive to very small and very light inputs, and runs very smoothly. It is used in follow-up controls where the signals come from receiver rotors and where the exact amount of turning is very important.

The jewel differential is designed to operate only small mechanisms with light loads, such as electrical contacts.

CAMS

CONSTANT LEAD CAM

RECIPROCAL CAM

SECANT CAM

SQUARE CAM

FLAT BALLISTIC CAM

BARREL BALLISTIC CAM

Cams have such different shapes and sizes and do so many different jobs that it is difficult to see what they have in common.

All of them have in common some kind of curved surface—such as a groove or a ridge, or a contour. The curved surface is positioned by the *input*. Each point on the curved surface represents a different *output* value.

Every cam also has some device like a roller or a ball called a "follower," which bears against the curved surface. At any given position of the cam, the follower is pushed by the curved surface into a position which registers the *output* value for that point of contact.

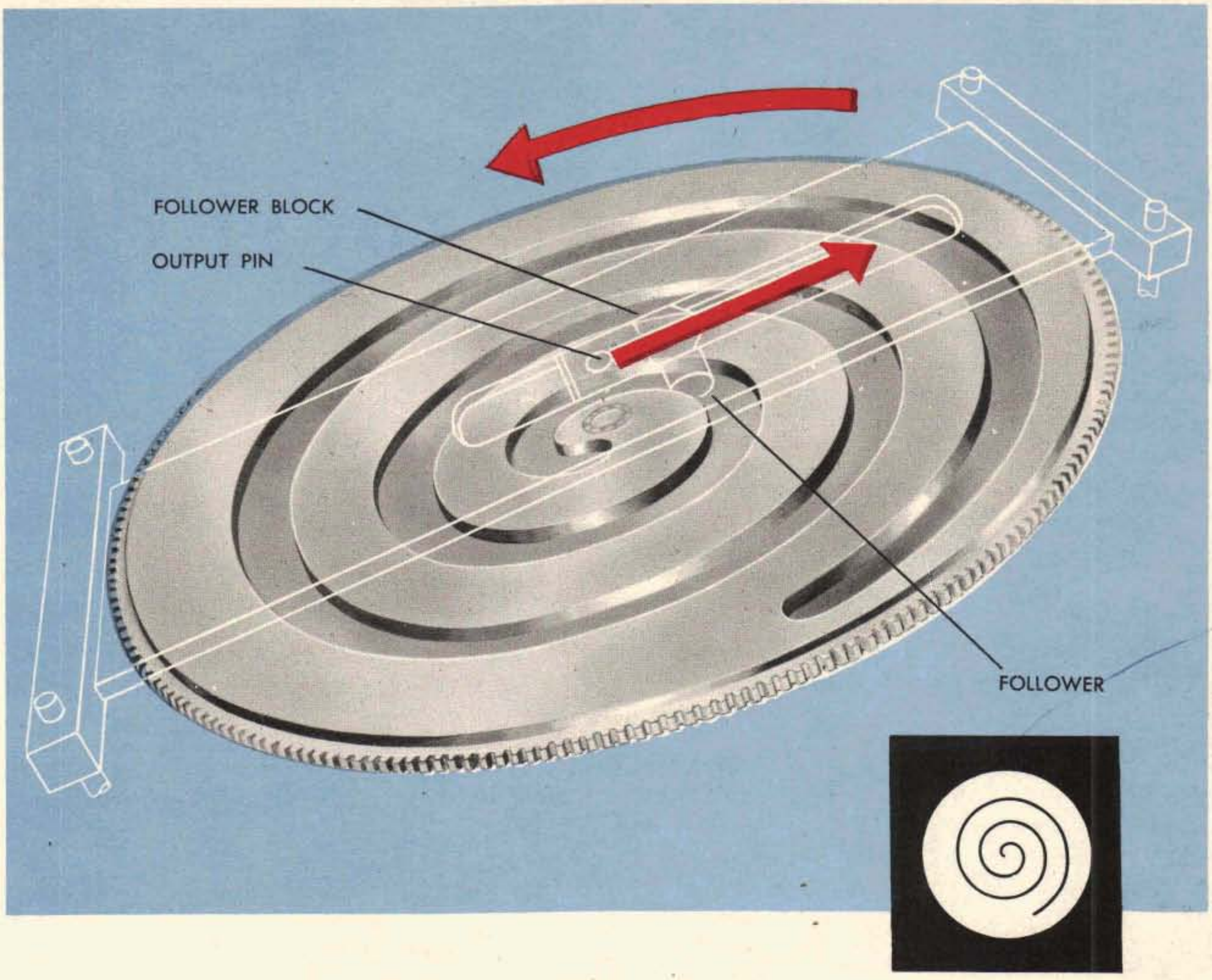
THE CONSTANT LEAD CAM

The simplest cam has a uniform or "constant lead" spiral groove. Each point on the spiral corresponds to an output that is directly proportional to the input. If the input is own ship speed in knots, each point on the groove will simply represent a different speed from 0 to, say, 45 knots.

COMPUTING CAMS

In all other cams, each point on the output surface represents a "function" of the input—such as a reciprocal, or a tangent, or a square of the input. These cams can be called *computing* cams to set them apart from the "constant lead" cam.

In computing cams, the follower position represents a quantity which is proportional to a function of the input. If, for example, the input of a tangent cam is *elevation angle,* the output is the *tangent* of elevation angle.



The spiral groove in a phonograph record carries the needle inward toward the center. If the record were run backward, the groove would move the needle from the center outward.

The groove in the spiral cam works in much the same way.

The CONSTANT LEAD CAM

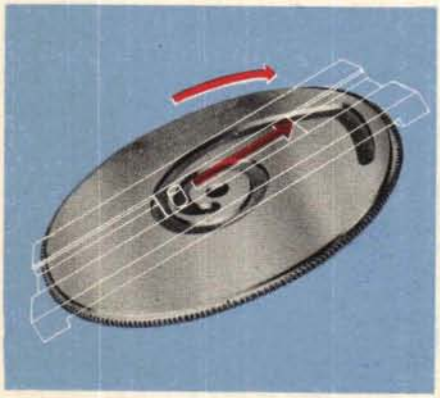
The constant lead cam consists of a spiral groove cut in a circular plate. If the cam is rotated in one direction, the spiral will force the follower block outward from the center along a straight slot. If the plate is turned in the opposite direction the spiral will force the follower block inward, toward the center.

The follower itself never travels to the center of the cam, but the *output pin* is offset on the follower block so that it can be positioned directly over the center of the cam. This is the *zero position* of the output pin.

The cam *output* is the distance from the center of the cam to the *output pin.*

The constant lead cam is a SPECIAL CASE. ITS OUTPUT IS SIMPLY A STRAIGHT MOTION OF THE FOLLOWER DIRECTLY PROPORTIONAL TO THE ROTARY MOTION OF THE INPUT. All other cams compute a FUNCTION of the input.

This is a RECIPROCAL CAM



One of the easiest ways to divide one number by another *mechanically* is to *multiply* the first number by the reciprocal of the second number.

THE RECIPROCAL OF A NUMBER IS 1 DIVIDED BY THAT NUMBER.

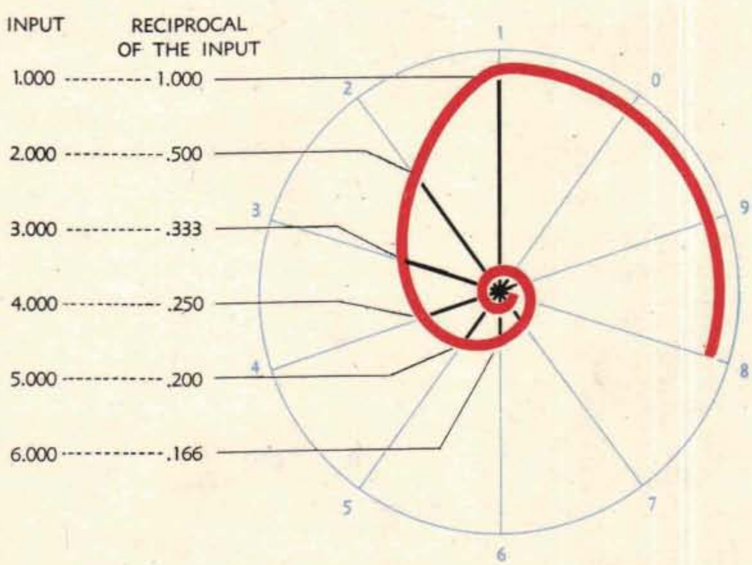
The reciprocal of 1 is 1; the reciprocal of 2 is ½, and so on.

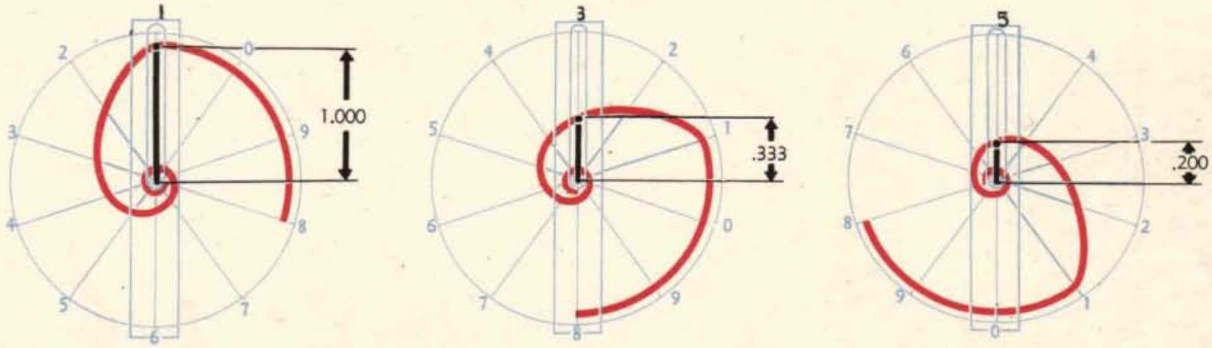
These reciprocals can also be expressed in decimals; the reciprocal of 1 is 1.00; the reciprocal of 2 is .500; the reciprocal of 3 is .333.

Obviously, dividing one number by another is the same as multiplying the first number by the reciprocal of the second:

$$\frac{a}{b} = a \times \frac{1}{b}$$

A reciprocal cam can be made by laying out reciprocal values along radii and connecting them by a curved groove.





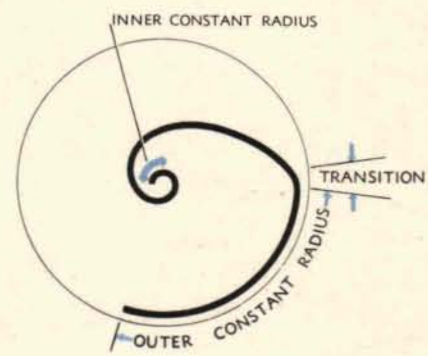
To get the reciprocal of a number the cam is turned to the position corresponding to that number. The output pin on the follower will then be a distance from the center corresponding to the reciprocal of the number.

In goes the number—out comes the reciprocal.

Notice that the follower travels along a straight line from the center to the edge of the cam. This type of follower is called a "radial" follower.

THE "RUNOUT"

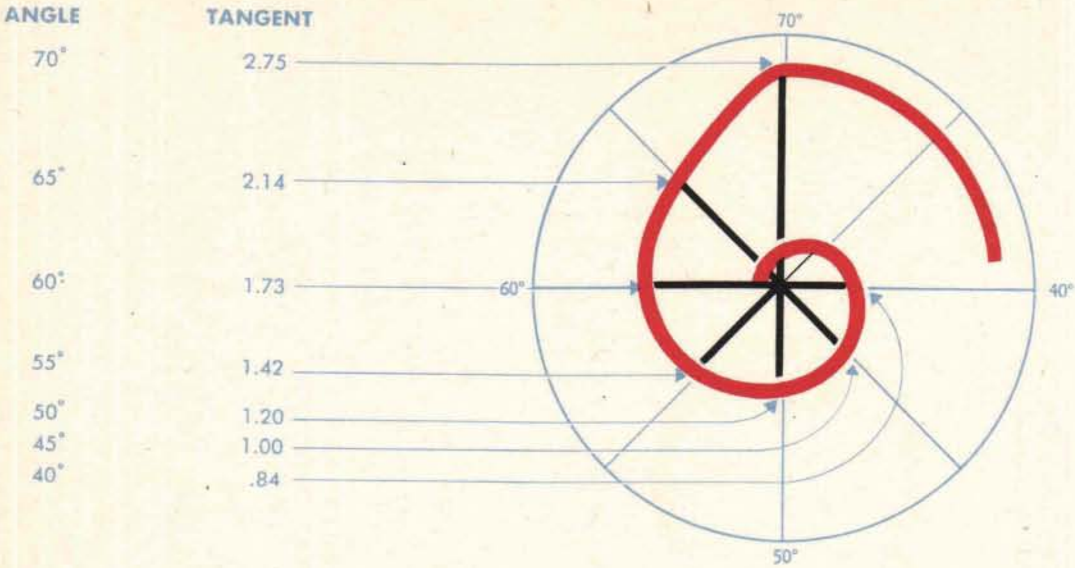
Often cams cannot be cut to compute an output for *all* values of the input. So they are cut for values between certain limits.



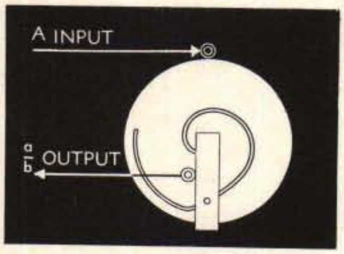
When these limits are reached, the follower passes onto the "runout." The runout consists of a transition section and usually a constant radius section.

While the follower is on a constant radius it remains the same distance from the center and there is no change in the output as the cam is turned.

Computing cams generally have a runout section at both ends of the computing section. So there may be an *inner* constant radius as well as an outer one.

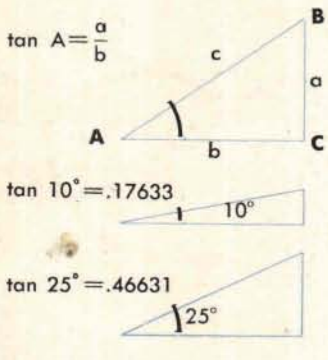


The TANGENT CAM is one of the TRIG CAMS



Almost any table or values can be cut into a cam. Grooves can be cut to give most of the Trigonometric Functions. The tangent cam is an example.

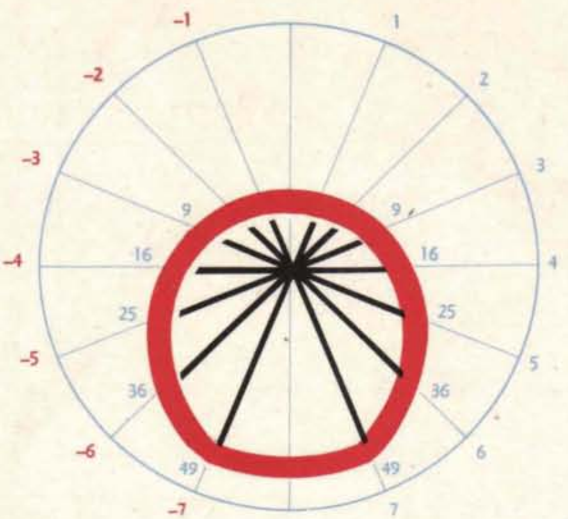
Except for the special tangent grooving, the tangent cam is like any other grooved cam. It can be mounted and used in exactly the same way. Its job is to give the tangent of an angle. The input is an angle—the output is the tangent of that angle.



Remember?

In a right triangle, the tangent of either of the two acute angles is the side opposite the angle divided by the side next to the angle.

This value changes, of course, as the angle changes. It increases rapidly as the angle becomes greater.



Here is a SQUARE CAM

The square cam works like the trig cams, but instead of a trig function it gives the square of any number.

If the input is 1 the output will be $1^2 = 1$

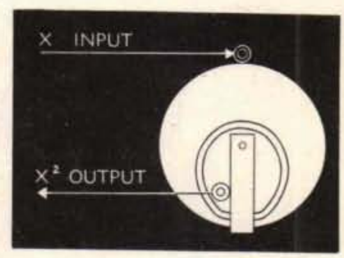
If the input is 2 the output will be $2^2 = 4$

If the input is 3 the output is $3^2 = 9$

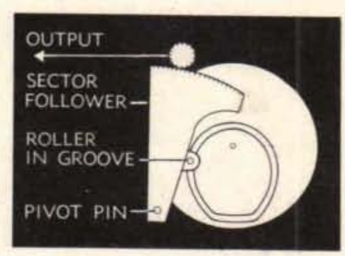
It also works for negative values:

If the input is -3 the output is $(-3)^2 = 9$, and so on.

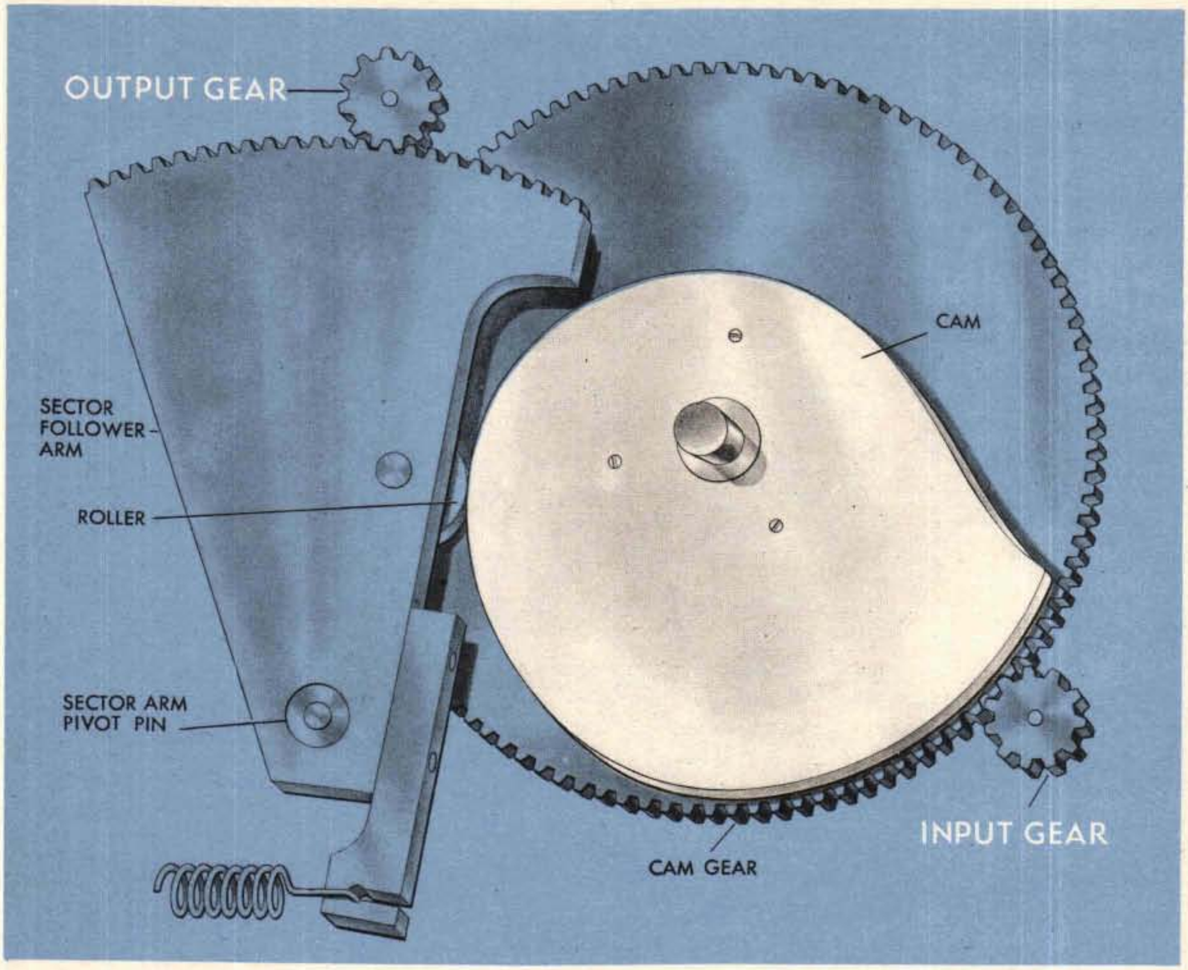
The output of a square cam is always positive.



A RADIAL follower similar to those already shown may be used with the square cam.



A SECTOR type follower may also be used. In this case the output is not a straight distance. With a sector type follower the output is the *angle* through which the sector arm has moved from its zero position. The cam groove, in this case, is slightly different from that used with radial followers.



A FLAT BALLISTIC CAM

The EDGE of this cam does the computing. It has no grooving.

The input gear turns the cam gear. The cam is mounted on the cam gear and turns with it.

A roller on the output sector arm is held against the edge of the cam by a spring at the bottom of the sector arm.

The distance from the center of the cam gear to the edge of the cam surface is different at each point around the cam, so the roller is pushed back and forth as the cam turns.

This movement of the roller pivots the sector arm, which turns the output gear.

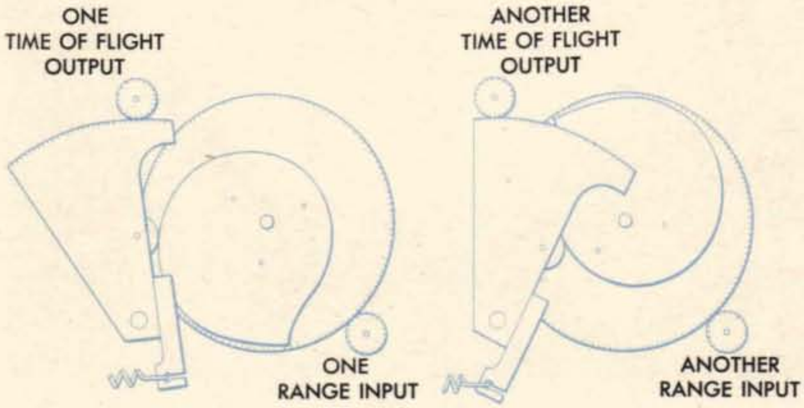
The Time of Flight Cam for surface fire is a good example of a flat ballistic cam.

In surface fire the time of flight of a shell is a function of range (advance range, to be more exact).

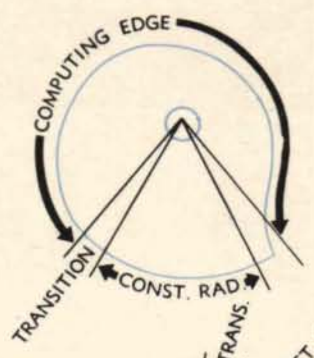
The greater the range, the longer the time the shell takes to reach the target, but the time does not increase in direct proportion to the advance range.

The input to the time of flight cam is advance range, which turns the cam gear. The cam moves the sector arm. The sector arm turns the output gear.

The output from the cam is time of flight, because the cam is shaped so that the POSITION OF THE OUTPUT GEAR ALWAYS CORRESPONDS TO THE TIME OF FLIGHT OF THE SHELL FOR THE VALUE OF THE ADVANCE RANGE INPUT.

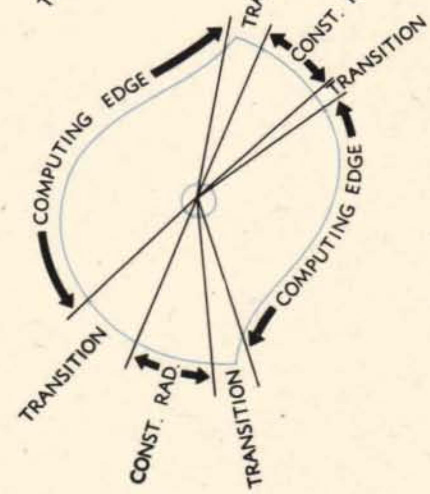


Usually a flat cam is not cut to give accurate outputs all the way around its edge. The accurate part is the computing edge, the rest is constant radius and the transition between the computing edge and the constant radius.

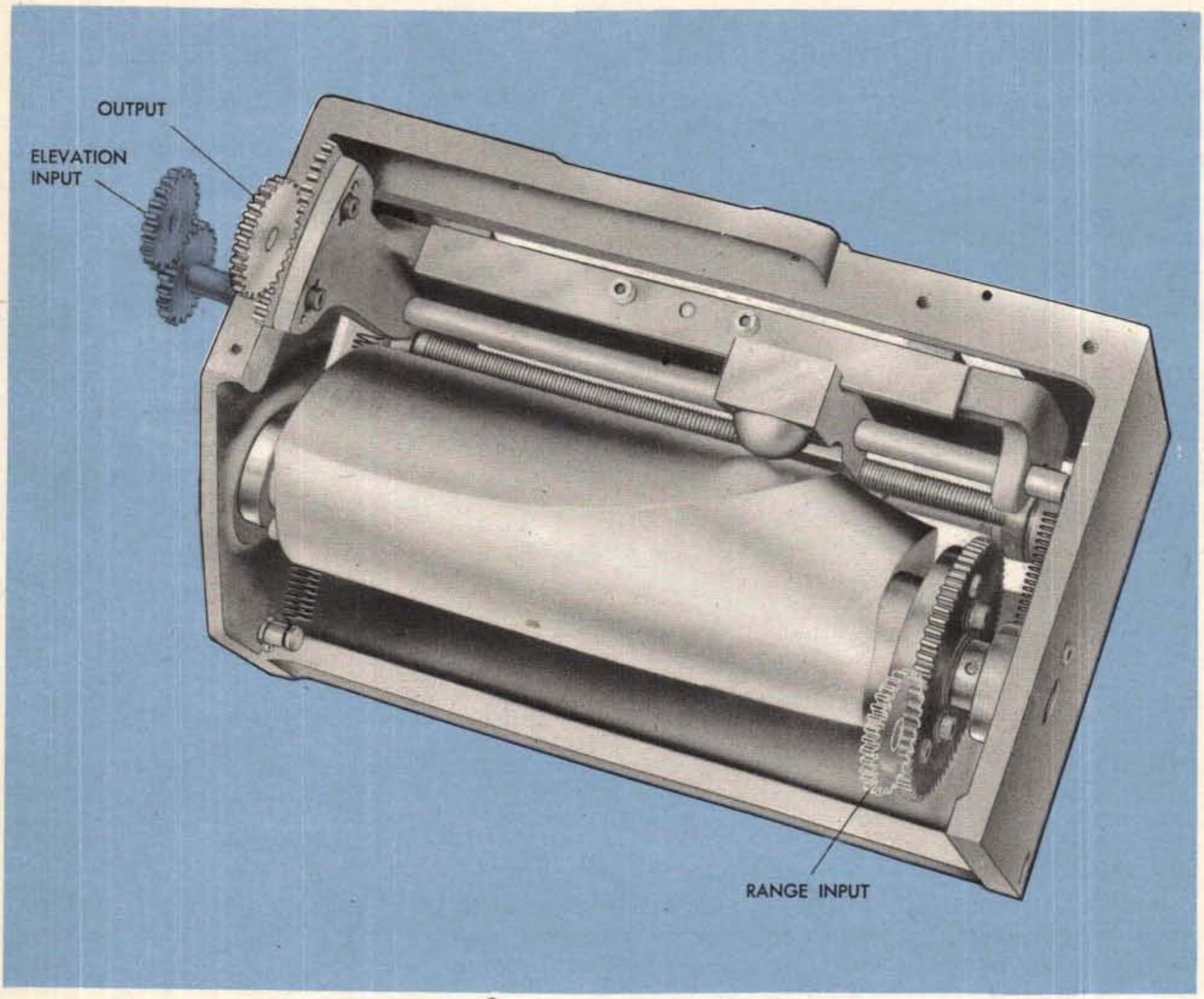


Sometimes two completely independent functions are cut on one cam, one function on each half. The outputs represent different functions of the input, for example, time of flight for two different kinds of projectiles, or two different powder charges.

To change from one set of values to the other, the cam is simply turned around 180°. The 180° change in position is put in by hand through a differential in the cam input line.



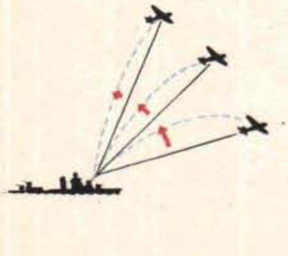
A BARREL BALLISTIC CAM



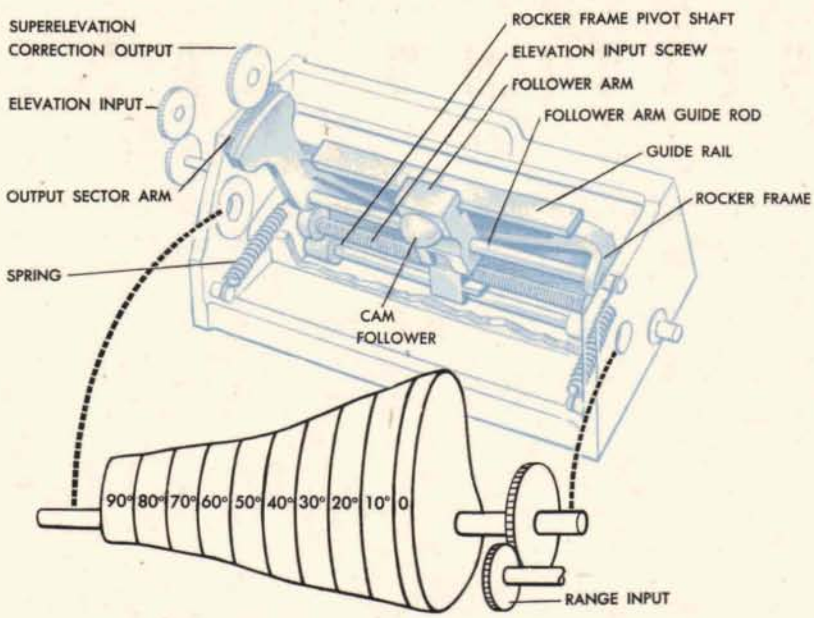
The BARREL CAM computes a *single* output which is a function of TWO different and independent inputs.

An example is the ballistic cam which computes the correction to gun elevation for fall of the projectile due to gravity. This correction is called "superelevation." Superelevation is a function of both advance range and elevation.

Superelevation *increases as advance range increases,* though not in direct proportion.



Superelevation *decreases as advance elevation increases,* again not in direct proportion.



The barrel cam is like a series of different shaped thin flat cams stacked side by side.

Each flat cam would give values of superelevation correction for all values of range at ONE ELEVATION ONLY. There would have to be a separate cam for each elevation angle.

The shape of the barrel cam varies gradually from one end to the other in such a way that EACH CROSS SECTION APPROXIMATELY REPRESENTS A DIFFERENT ELEVATION.

The elevation input gear turns the long screw which moves the cam follower along its guide selecting the cross section of the cam to be used. As the surface of the cam is curved, movement of the follower ALONG the cam PIVOTS the follower arm and guide. The follower arm is held against the cam by a spring.

The range input turns the cam, which also changes the position of the follower arm and guide.

The position of the output gear depends on two things:

a. The position of the follower arm along the cam

b. and the turning of the cam itself.

Each point on this particular cam surface, then, represents the superelevation correction for a *particular range and a particular elevation.*

Time of flight and fuze time for air targets are computed by similar cams.

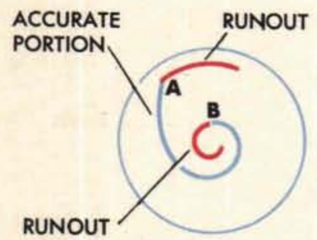
NOTE: The barrel cams in the Computer Mark 1 and Range Keeper Mark 10 do not compute their outputs directly. Instead they compute the difference between a given function and a straight line. How this is done is explained in Ordnance Pamphlets 1064 and 1065.

SETTING CAMS

On all trig cams and the reciprocal cam, the cam path is steeper in one place than another. The two important points for setting are:

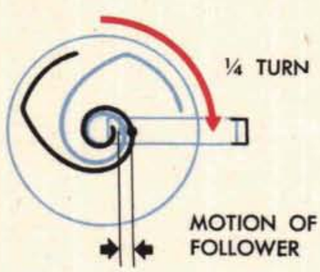
1. The point of greatest steepness
2. The point of least steepness

Here is a typical cam

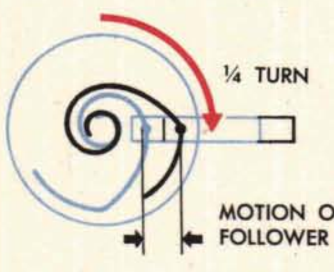


The accurate portion of this cam's path lies between points *A* and *B*.

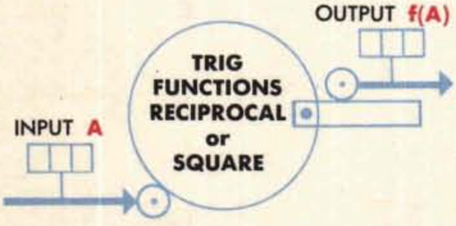
The rest of the cam path is known as "runout" and is present so that the cam follower will not hit the end of the cam.



When the follower is at the point of least steepness (on this cam this point is near the INNER CONSTANT RADIUS), a large movement of the cam produces little motion of the follower.



When the follower is at the point of greatest steepness (on this cam this point is near the OUTER CONSTANT RADIUS), the same movement of the cam produces greater movement of the follower.



The problem of setting a cam becomes one of setting the cam follower.

The cam input is *A*.

The cam output is a function of *A*, usually written: $f(A)$.

The function depends upon the shape of the cam. If it were a tangent cam, the output would be tangent *A;* if it were a reciprocal cam, the output would be $1/A$, etc.

To set a computing cam

Assume that the steepest part of the cam is at an input of 60, and that at this point $f(60) = 2.00$.

1. Put the input counter on 60 and wedge the input.
2. Run the cam follower to the point of greatest steepness.

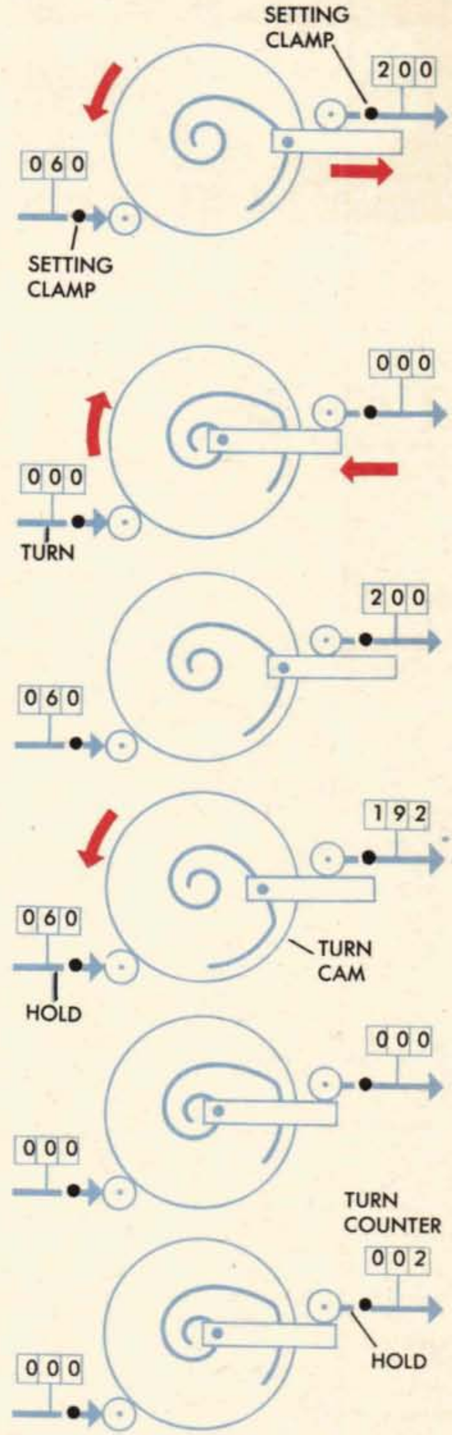
NOTE: The computer's setting notes will give the input counter reading and approximate cam position for that reading.

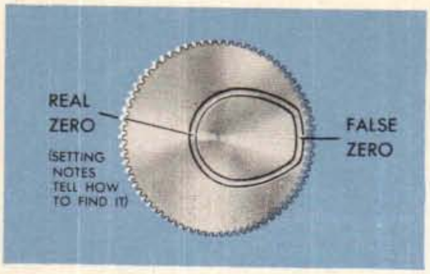
3. Slip-tighten the input setting clamp.
4. Put the output counter on 2.00 which equals $f(60)$.
5. Slip-tighten the output setting clamp. The input is now approximately set.
6. Now run input *A* until the input counter has the reading for a very flat part of the cam. In this case the reading used is 0.
7. Set the reading of the output counter. It should be $f(0)$ which in this example equals zero.

NOTE: The output is now approximately set.

8. Now return the input counter to 60 and observe the *output counter reading.*
9. Here the setting is correct. The input counter shows 60, the output counter reads 2.00 and the cam follower is properly placed at a steep point on the cam.
10. Here the setting is incorrect. The input counter reads 60. The output counter reads 1.92. This means that the follower is incorrectly positioned.
11. To correct this input error, hold input *A* at 60 and slip the cam through the setting clamp until the output counter reads 2.00.
12. Tighten the input setting clamp.
13. Now run input *A* counter to 0. Observe the output counter reading.
14. Here the output counter has the proper reading, zero.
15. Here the output counter reads incorrectly, 2.
16. To correct, hold the cam output and slip counter through to read zero.

NOTE: This, of course, will cause the cam output to be in error at the 60 reading by the amount the output counter has just been moved. Refine the two settings further by repeating steps 8, 11, 13 and 16 until minimum error is observed in steps 8 and 13.



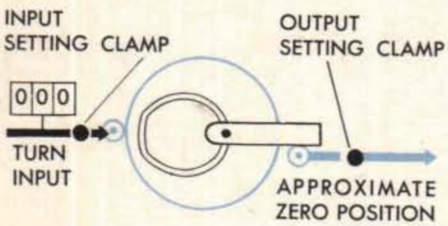


Setting the SQUARE CAM

Because of the shape of this cam two points on it appear to be zero positions. Only one of these, however, is the real zero position.

NOTE: The computer's setting notes give the zero position for each square cam.

Once the *real* zero position has been identified the cam may be set.



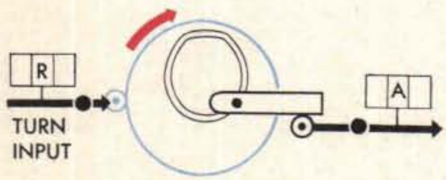
1 Turn the input to the square cam until the counter reads zero.

2 Turn the cam until it is approximately at its real zero position.

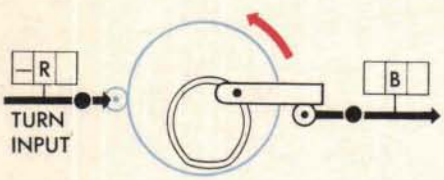
3 Put the output counter at zero.

Slip-tighten the input setting clamp and the output setting clamp.

The following steps are usually necessary to refine the above approximate setting.



4 Turn the input shaft to move the follower from 0 to *R*. Record both the input and the output readings.



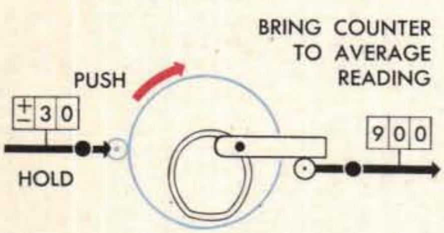
5 Now move the follower in the opposite direction to $-R$. Record both the input and the output readings.

6 Fill in the following table: for example:

INPUT READING	OUTPUT READING	INPUT READING	OUTPUT READING
R	A	$+30$	A
0	0	0	0
$-R$	B	-30	B

7 Here the cam was set incorrectly and readings *A* and *B* do not agree:

INPUT READING	OUTPUT READING
+30	+880
0	0
−30	+920



8 To correct first get the average reading by adding the output readings and dividing by 2.
$880 + 920 = 1800 \div 2 = 900$

9 With the cam input counter held at +30, slip the cam through the input setting clamp until the output counter is on the average reading. Check that with the input counter at −30 the output has this same average reading. Tighten both clamps.

10 Here the cam was set correctly. *A* and *B* are equal both in quantity and in sign:

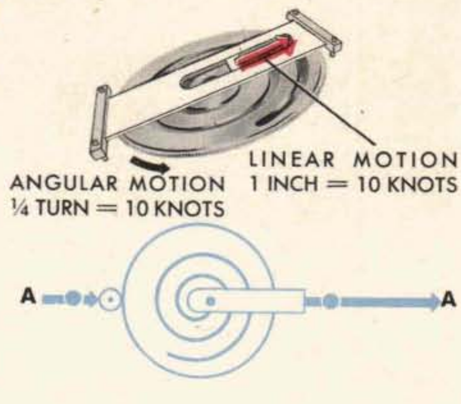
INPUT READING	OUTPUT READING
+30	+900
0	0
-30	+900

Setting the CONSTANT LEAD CAM

On a constant lead cam the input is *A*, and the output is *A*. The only difference is that an angular motion is converted to a linear motion.

To set a constant lead cam requires only finding the "zero position" of the follower. With the follower in this position the input and output counters are set at zero.

Constant lead cams are used in component solvers. To set a constant lead cam, see the component solver setting notes.



Setting the FLAT BALLISTIC CAM

Ballistic cams must be set very accurately. These cams are set with a setting rod.

1 Insert the setting rod.

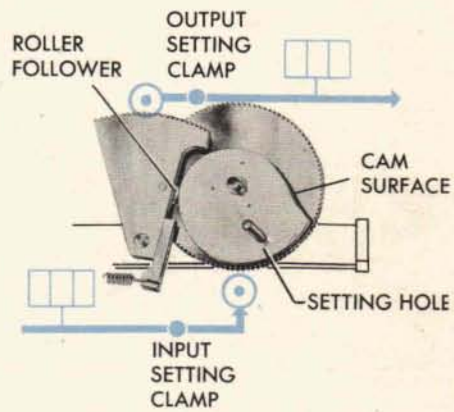
   NOTE: The computer's setting notes tell how to use the setting rod on the cam to be set; it also gives the counter settings which should be made when the rod is inserted.

2 Turn the input until the counter reading agrees with the specified reading for the setting rod position.

3 Put the output counter at the value give in the computer setting notes.

4 Tighten the input setting clamp and the output setting clamp.

5 Remove the setting rod.



Setting the BARREL CAM

1 Insert the setting rod. It must go through the follower block and into the cam.

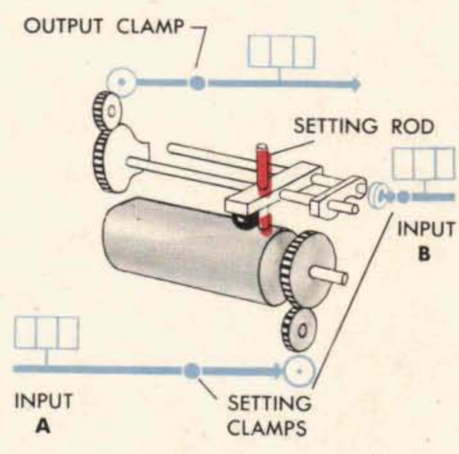
2 Put *A* and *B* input counters on readings given on the ballistic unit for the setting rod position.

3 Tighten the input clamps.

4 Put the output counter on the reading given in Computer's setting notes.

5 Tighten output clamp.

6 Remove the setting rod.

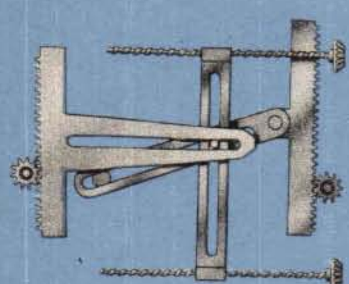


MULTIPLIERS

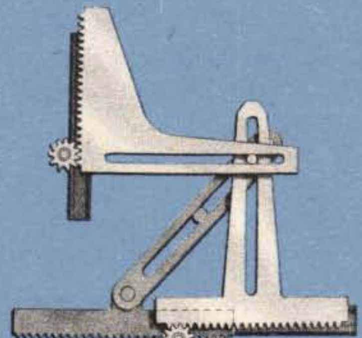
In solving a fire control problem it is often necessary to multiply two continually changing values to produce a continuous series of products. The device that accomplishes this is called a *multiplier*. There are several types of multipliers but they usually produce a solution through the use of similar triangles.

For mechanical reasons it is more convenient to build a multiplier that delivers a fixed fraction of the answer, such as a tenth or a twelfth, rather than the complete numerical value required. This fraction can be "stepped up" to produce a complete answer by the proper choice of input and output gearing, but this is seldom necessary.

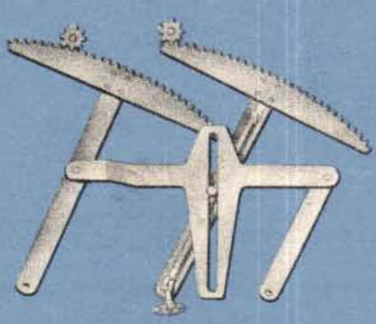
MULTIPLIERS CAN TAKE TWO CONTINUALLY CHANGING INPUT VALUES AND DELIVER AN OUTPUT THAT IS *PROPORTIONAL* AT EVERY INSTANT TO THE PRODUCT OF THE TWO CHANGING INPUTS.



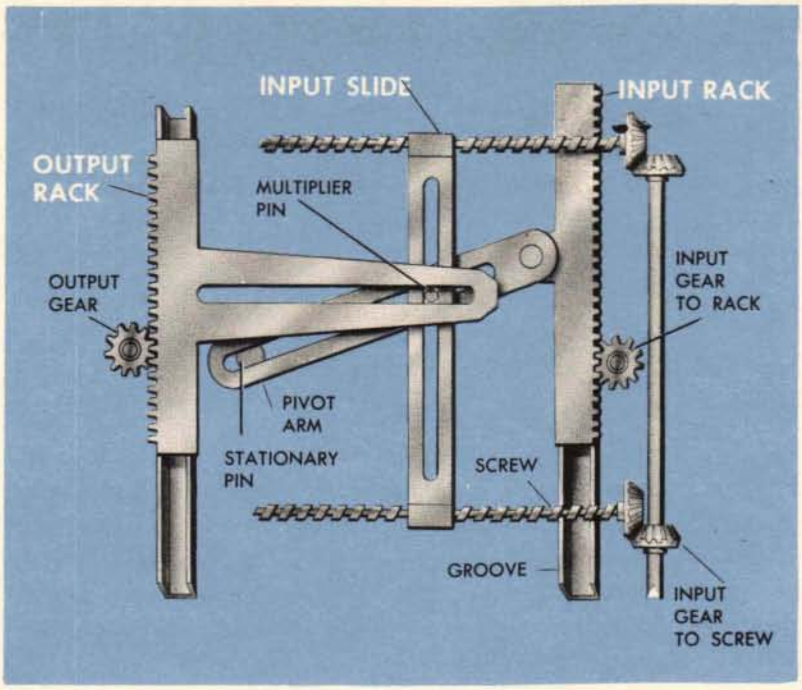
SCREW TYPE MULTIPLIER



RACK TYPE MULTIPLIER



SECTOR TYPE MULTIPLIER



NOTE:
The input slide of most screw-type multipliers is grooved rather than slotted. The slide is pictured as slotted in order to show more clearly the relationship and movement of the multiplier's parts.

The SCREW TYPE MULTIPLIER

The screw-type multiplier has two inputs: a **SLIDE** and a **RACK**.

The *input slide* is moved back and forth by two long lead screws.

The *input rack* is moved up and down by a spur gear.

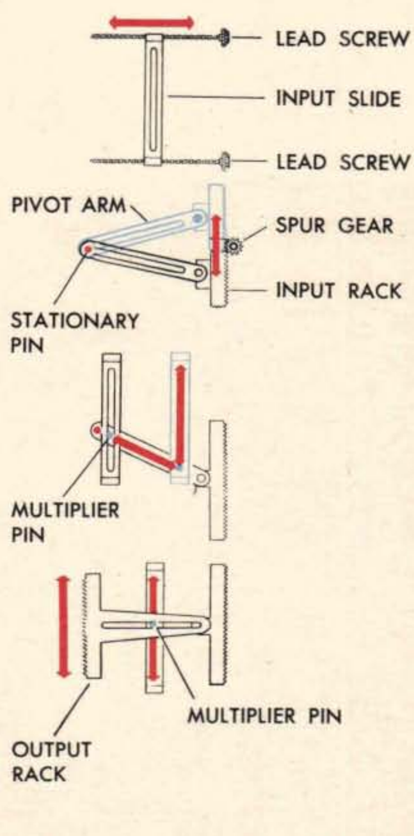
The input rack moves a slotted pivot arm that pivots around a stationary pin as the input rack is moved.

A pin called the "multiplier pin" is mounted in the slots of the input slide and the pivot arm where these slots cross. The position of this pin is changed by movement of the input slide or the input rack.

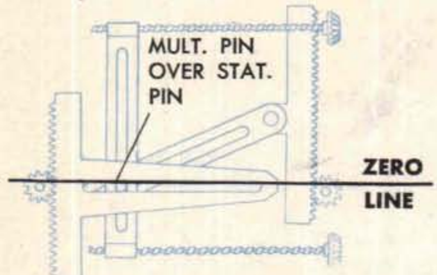
The multiplier pin also fits into a slot in the **OUTPUT RACK**. As it changes position this pin moves the output rack up or down.

THE POSITIONS OF THE *INPUT SLIDE* AND THE *INPUT RACK* REPRESENT THE TWO VALUES TO BE MULTIPLIED TOGETHER.

THE POSITION OF THE *OUTPUT RACK* REPRESENTS THE OUTPUT VALUE, WHICH IS ALWAYS PROPORTIONAL TO THE *PRODUCT* OF THE TWO INPUTS.

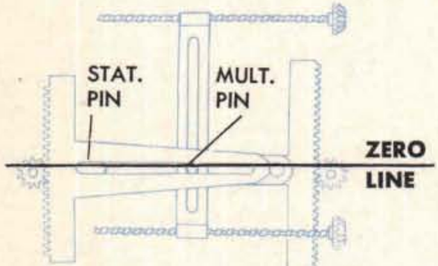


How it multiplies



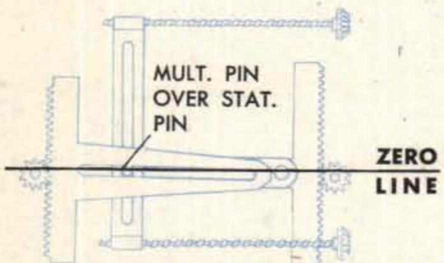
ZERO POSITION OF INPUT SLIDE

Suppose the lead screws are turned until the multiplier pin lies directly over the stationary pin. This is known as the *zero position* of the ***input slide***, since, with the slide in this position, movement of the input rack will not produce any movement of the output rack.



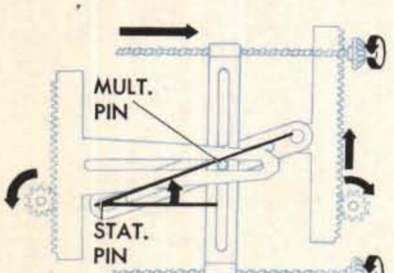
ZERO POSITION OF INPUT RACK

Similarly, if the slot in the pivot arm is positioned parallel to the slot in the output rack, no amount of motion of the input slide can cause any vertical motion of the multiplier pin or of the output rack. This position is known as the *zero position of the input rack.*



ZERO POSITION OF BOTH INPUTS

Here are both inputs at their zero position.



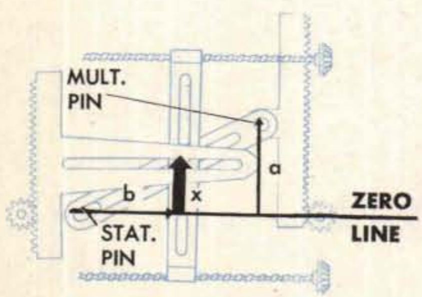
Now, suppose both input gears turn a few revolutions in the directions indicated.

The input slide will move to the right.

The input rack will move up its groove, bringing the pivot arm into an angular position.

The multiplier pin will be pushed to its new position by the combined action of the pivot arm and the slide.

This pin will move the output rack, and the output rack will turn the output gear.

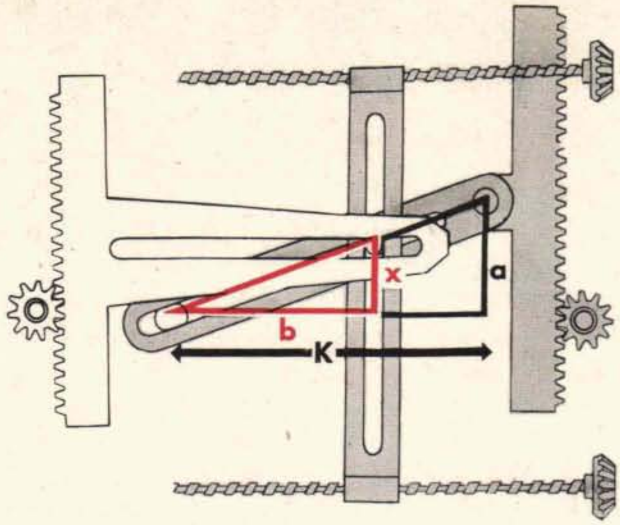


Now, label the distances each part has traveled from the zero line:

The input rack has moved up a

The input slide has moved over b

The output rack has moved up x



If these distances are drawn on the diagram of the multiplier, they form two right triangles.

IN THE SMALLER TRIANGLE—the HEIGHT, x, is the distance the output rack moved from zero. The BASE, b, is the distance the input slide moved from zero.

IN THE LARGER TRIANGLE—the HEIGHT, a, is the distance the input rack moved from zero. The BASE, K, is the fixed distance along the zero line from the stationary pin to the pivot on the input rack.

Notice that the larger triangle is the same *shape* as the smaller triangle. The only difference between the triangles is that one is larger than the other. They are *similar* triangles.

Now it can be seen that the ratio between the height and the base of the smaller triangle is equal to the ratio between the height and the base of the larger triangle.

That is:

$$\frac{x}{b} = \frac{a}{K}$$

Multiplying both sides by b:

$$\frac{bx}{b} = \frac{ba}{K}$$

Then:

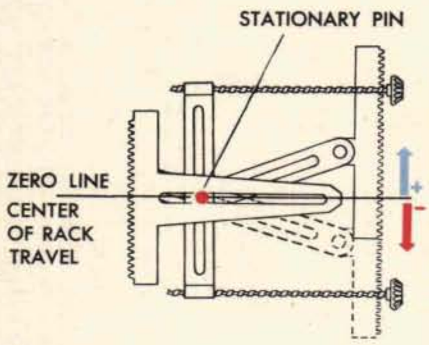
$$x = \frac{ba}{K}$$

This equation shows that the distance the output rack moved from zero is equal to the product of the distances the input slide and rack have moved from zero, DIVIDED BY A CONSTANT.

IN OTHER WORDS, THE OUTPUT IS ALWAYS PROPORTIONAL TO THE PRODUCT OF THE TWO INPUTS.

Since K is a fixed distance, it is a CONSTANT value in each multiplier. Its effect is taken care of by proper choice of input and output gearing for the multiplier.

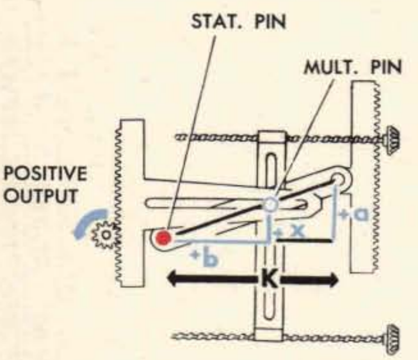
How it handles both



Suppose the rack input is to be a rate or an angle which can have *negative* values as well as *positive* ones. The arrangements of the parts must then be changed slightly to allow for this. The *stationary pin* must be located so that the zero position of the input rack is in the *middle of the rack travel.* That is, the input rack can be moved UP OR DOWN from its zero position. This is the usual location of the stationary pin.

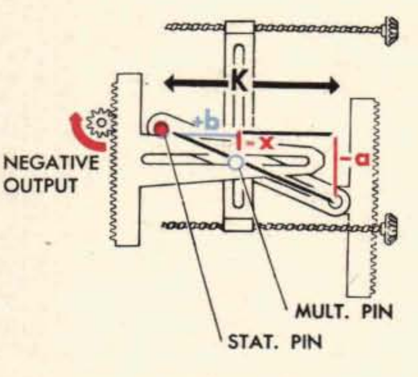
Now, if the input is considered to be *positive when the rack is above its zero position,* the input must be *negative when the rack is below its zero position.*

The same rule must also apply to the output rack. That is, a position of the *output rack above zero represents a positive output* and a position of the *output rack below zero represents a negative output.*



Here both inputs are positive so the output is positive

$$x = \frac{(+a)\ (+b)}{K} \qquad x = +\frac{ab}{K}$$

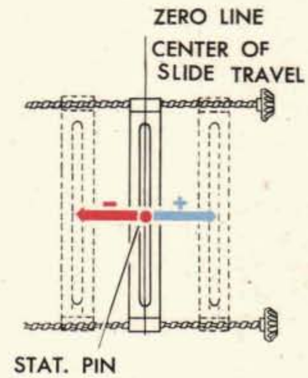


Here the screw input is positive but the rack input is negative so the output is negative

$$x = \frac{(-a)\ (+b)}{K} \qquad x = -\frac{ab}{K}$$

POSITIVE and NEGATIVE values

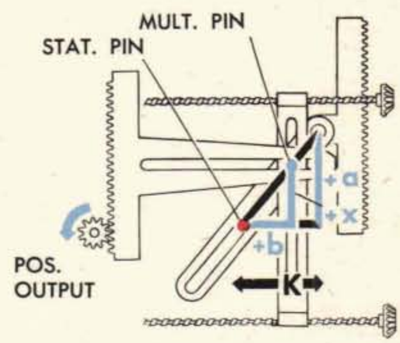
In the same way the multiplier can be arranged to handle a positive or negative *input* to the slide. This is accomplished by locating the stationary pin toward the middle of the screw travel. The slide may now travel in either direction from the zero position.



Then, if positions of the slide to the right of the pin represent *positive* input values, positions of the slide to the left of the stationary pin represent *negative* values of that input.

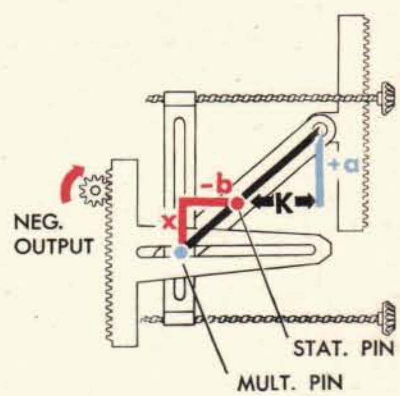
Here both inputs are positive:
The output is positive

$$x = \frac{(+a)\,(+b)}{K} \quad \text{or} \quad x = +\frac{ab}{K}$$



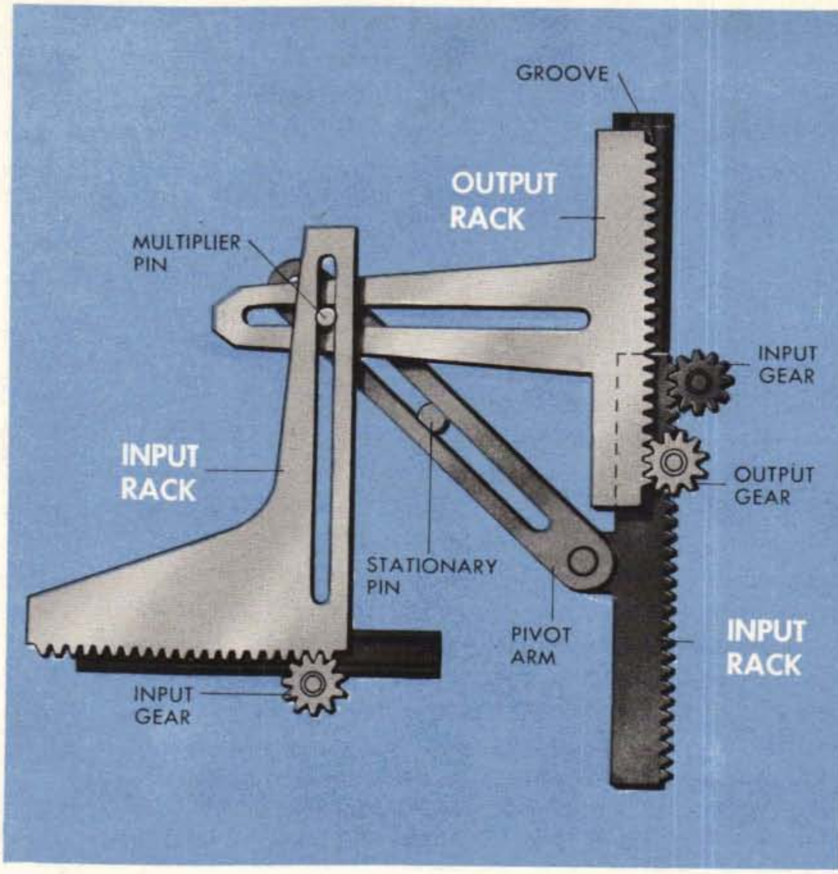
Here the rack input is positive,
The slide input is negative,
So the output is negative

$$x = \frac{(-b)\,(+a)}{K} \quad \text{or} \quad x = -\frac{ab}{K}$$



From these examples it can be seen that the *stationary pin may be located any convenient place* on the multiplier. For any particular multiplier the exact location of the stationary pin depends mainly upon the values that must be handled by the two inputs.

It is important to note that *the zero position of the input slide is always directly over the stationary pin wherever the stationary pin is located.*



The RACK TYPE MULTIPLIER

There are two major differences between the rack type and the screw type:

1 The input slide and the lead screws of the screw type have been replaced by a rack like the output rack. This is one input rack. It is mounted in guide rails so that its slot is always at right angles to the slot in the output rack.

2 The output rack is generally mounted on the same side of the multiplier as the second input rack. However, the position of the slot is still the same as in the screw type and the operation is the same.

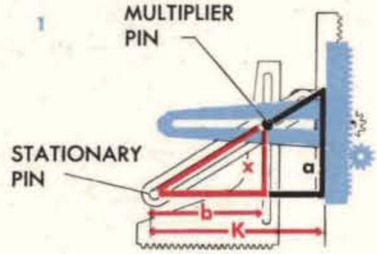
BASIC MECHANISMS OP 1140

1 This multiplier works just like the screw type. The same triangles are formed and the same equations apply to those triangles.

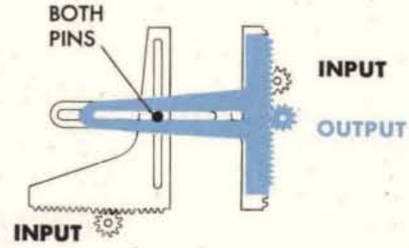
$$\frac{x}{b} = \frac{a}{K} \quad \text{or} \quad x = \frac{ab}{K}$$

In other words, the output is always PROPORTIONAL to the product of the two inputs, just as it was in the screw type multiplier. Here the stationary pin is shown at one end of the pivot arm.

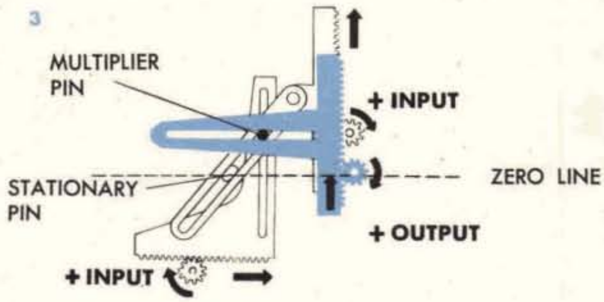
In the rack type multiplier the stationary pin is often in the CENTER of the pivot arm, but not always. It may be located anywhere along the pivot arm. In all diagrams except the first it is shown in the center of the pivot arm slot.



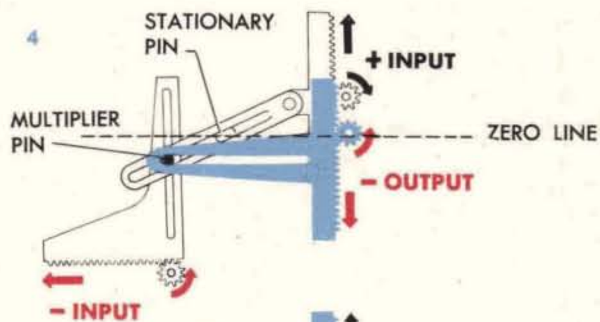
2 Here are all the parts in zero position. The multiplier pin is right on top of the stationary pin. Movement of any *one* input will leave the output at zero.



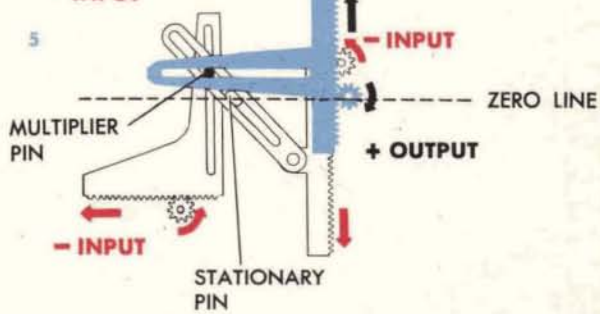
3 Here both racks move in a POSITIVE direction. The output is POSITIVE.



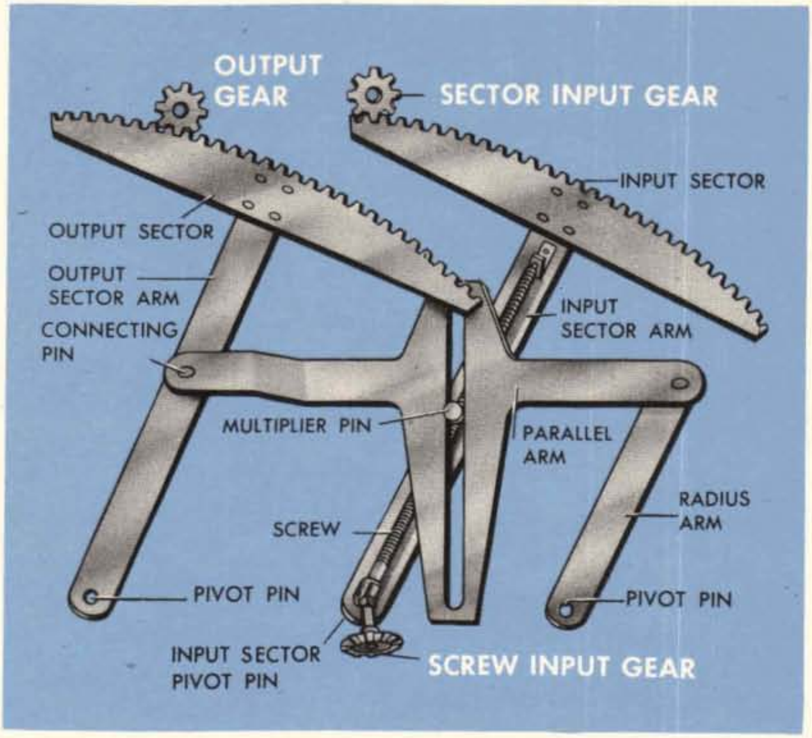
4 Here one input is POSITIVE, the other is NEGATIVE. The output is NEGATIVE.



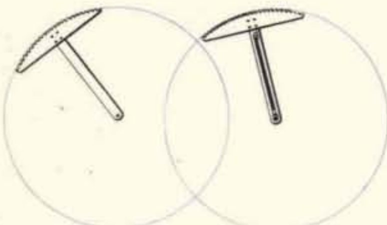
5 Here both inputs are NEGATIVE, so the output is POSITIVE.

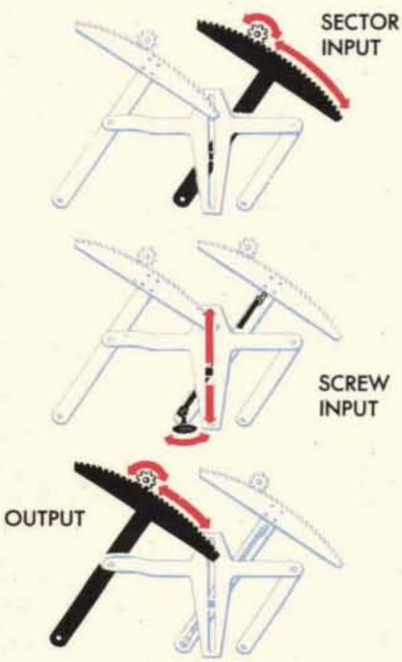


IN THE RACK TYPE MULTIPLIER, THE DISTANCE MOVED BY THE OUTPUT RACK IS PROPORTIONAL TO THE PRODUCT OF THE DISTANCES MOVED BY THE TWO INPUT RACKS.



The SECTOR TYPE MULTIPLIER





This multiplier is called the sector type because the long geared parts are sectors of circles. The centers of these circles are the pivot pins around which the sector arms swing.

There are two inputs:

One input positions the input sector arm.

The other input turns a long screw that is mounted on the input sector arm. The bevel gear turns this screw through a universal joint, so that it can drive the screw as the sector arm changes its angular position.

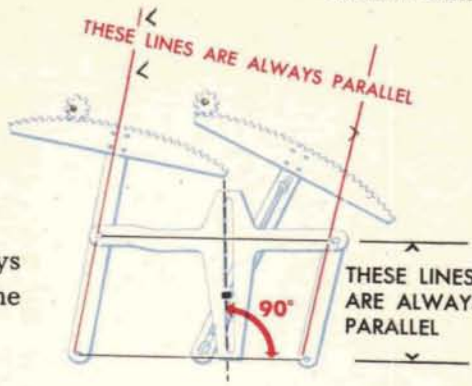
The multiplier pin is driven up and down the sector arm by the screw.

The position of the input sector arm and the position of the pin on the screw represent the two values to be multiplied.

One end of the parallel arm is mounted on the output sector, the other end is mounted on the radius arm.

The multiplier pin moves in the slot in the parallel arm and positions this arm. As the parallel arm is moved from side to side, it swings the output sector to a position representing the output.

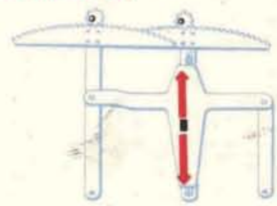
How the parts move



The slotted piece is called the parallel arm because it always moves parallel to a line through the three lower pivot pins. The slot is always PERPENDICULAR to that line.

The sector arms are in zero position when the lead screw on the input sector is parallel to the slot in the parallel arm. With the input sector arm at zero, movement of the pin will not move the output sector arm.

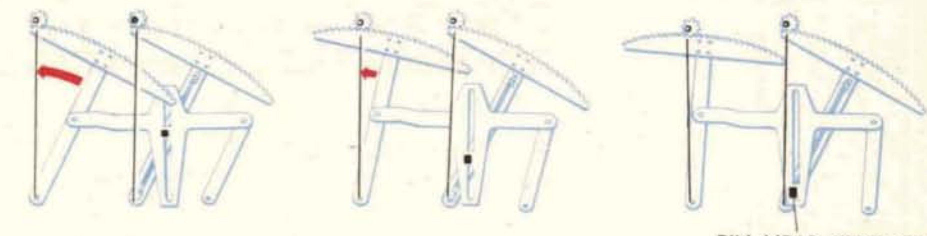
NO MOTION



INPUT SECTOR ARM IN ZERO POSITION

When the input sector arm is moved away from zero, any movement of the pin will move the output sector arm. The amount of output motion depends on the position of the multiplier pin along the screw.

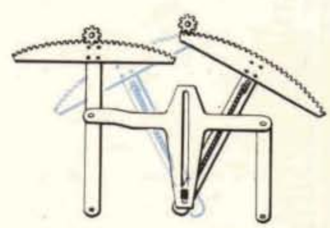
AS PIN MOVES DOWN, OUTPUT ARM MOVES TO ZERO POSITION



PIN NEAR ZERO POSITION

As the multiplier pin is moved down the screw toward the sector arm pivot pin, the output arm straightens up towards its zero position.

Zero position for the multiplier pin is right over the sector arm pivot pin. When the pin is at zero, motion of the input sector arm will not move the output arm.



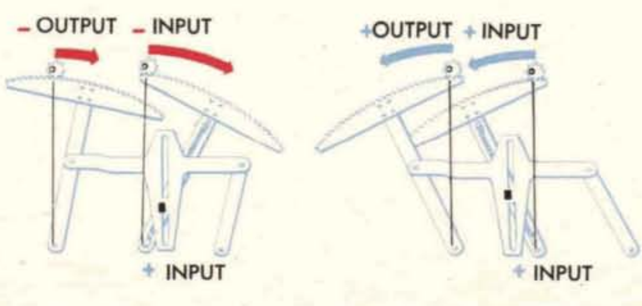
INPUT ARM MOVES IN EITHER DIRECTION FROM ZERO POSITION

The sector arm input moves in either direction from zero position. These two directions represent positive and negative inputs.

Since the pin moves only one way from its zero position, it can handle only positive inputs, or only negative inputs, but not both.

SECTOR INPUT CAN HANDLE BOTH POSITIVE AND NEGATIVE INPUTS

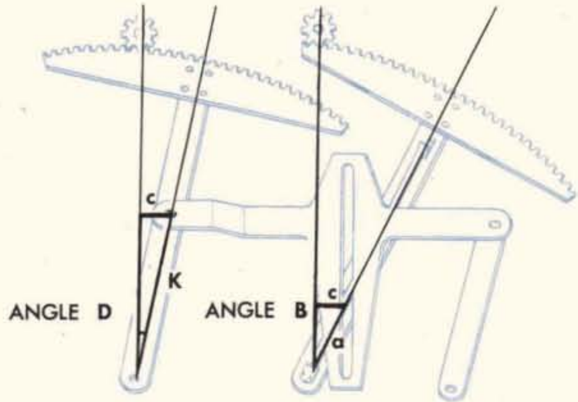
SCREW INPUT TAKES VALUES OF ONLY ONE SIGN



NOTE:

In some installations, the screw-type multiplier is constructed to allow the pin to travel a little below the zero position.

How the sector type works



Like the screw type multiplier, the sector type uses the relationship between triangles in performing a multiplication. These triangles are formed by movement of the sectors in response to changing inputs.

Assume that a combination of two inputs has caused the sectors to take the positions shown in the diagram. Two right triangles are formed. Each has one side of the same length, c.

In the LEFT HAND TRIANGLE the hypotenuse K is the fixed length between the pivot pin and the connecting pin.

In the RIGHT HAND TRIANGLE the hypotenuse is the distance, a, that the multiplier pin has moved away from the pivot pin.

Since the sine of an angle $= \dfrac{\text{opposite side}}{\text{hypotenuse}}$

then in the LEFT HAND TRIANGLE

$$\text{the Sine of angle } D = \frac{\text{side c}}{\text{hypotenuse } K}$$

Multiplying both sides of the equation by K produces:

$$K \text{ Sine } D = \frac{cK}{K} \quad \text{or, } K \text{ Sine } D = c$$

In the RIGHT HAND TRIANGLE

$$\text{the Sine of angle } B = \frac{\text{side c}}{\text{hypotenuse } a}$$

Multiplying both sides of this equation by a produces:

$$a \text{ Sine } B = \frac{ca}{a} \quad \text{or, } a \text{ Sine } B = c$$

Reviewing both equations,

since $K \text{ Sine } D = c$ and $a \text{ Sine } B = c$

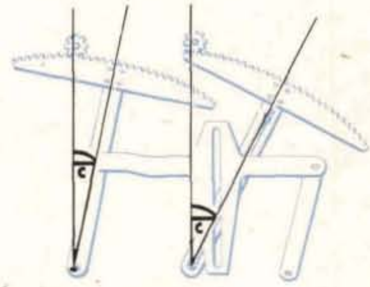
then $K \text{ Sine } D = a \text{ Sine } B$

Dividing both sides of this new equation by K produces:

$$\text{Sine } D = \frac{a \text{ Sine } B}{K}$$

Now to get rid of the Sines:

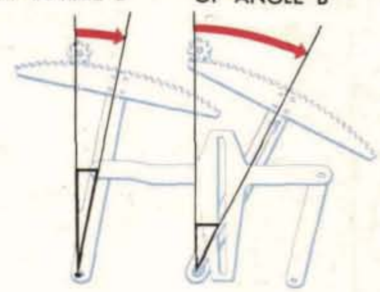
As shown in the Basic Mathematics chapter it is permissible to substitute the value of an angle in *radians* for the sine of the angle, when the angle is small. Here the angle may be as large as 20°. Such an angle is larger than is usual when the radian value is substituted for the sine. However, the resulting error is still considered acceptable.



LINE C IS NEARLY EQUAL TO RADIAN ARC

The equation now becomes:

$$\text{Angle } D \text{ in radians} = \frac{a \times \text{angle } B \text{ in radians}}{K}$$



LINEAR VALUES CAN BE SUBSTITUTED FOR ANGLES B AND D

Since these angles are expressed in radians, the radian values of angles B and D, which represent motion of the sectors, can now be substituted for the angles in each case.

Therefore, output D is the product of input a, multiplied by input B, and divided by constant K.

$$D = \frac{aB}{K}$$

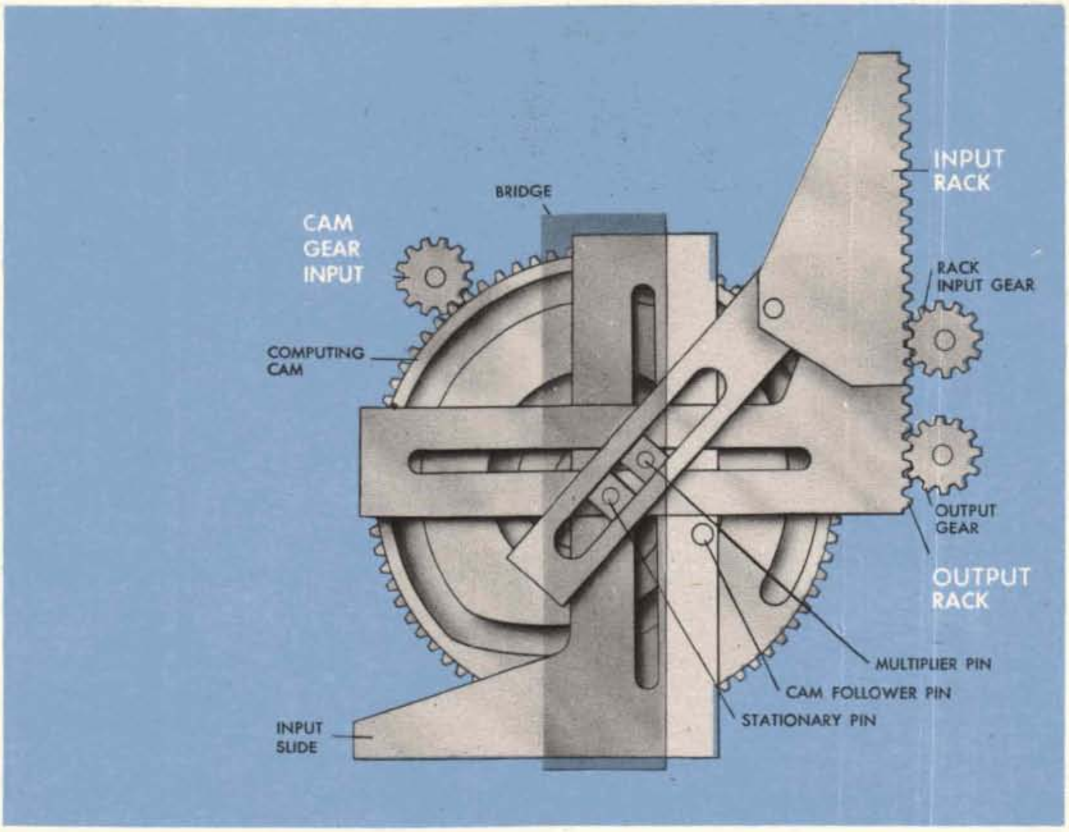
THE OUTPUT, THEN, IS PROPORTIONAL TO THE PRODUCT OF THE TWO INPUTS.

The constant K is taken into consideration by giving a suitable value to the output shaft, or by appropriate gearing.

Thus:

Output D is the product of input a, multiplied by input B

or: $D = aB$



SINGLE CAM COMPUTING MULTIPLIER

The cam type multiplier does more than just multiply two values together.

IT COMPUTES A FUNCTION OF ONE VALUE AND MULTIPLIES THAT FUNCTION BY A SECOND VALUE.

This multiplier is like the rack type multiplier except that one of the inputs is positioned by a cam instead of a rack.

The cam follower pin is mounted directly on the multiplier input slide. The cam used may be cut to compute any desired function of the cam input.

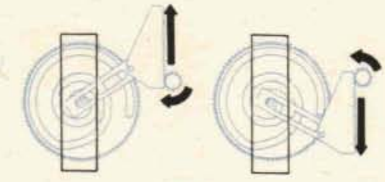
The mechanism works this way:

1 One input drives the input rack.

2 The other input drives the cam directly.

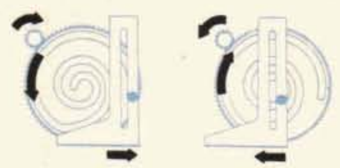
3 The cam positions the input slide according to the function for which the cam was cut. Thus the cam *output* becomes the slide *input*.

4 The position of the output rack represents a value which is proportional to the product of the cam output and the rack input.



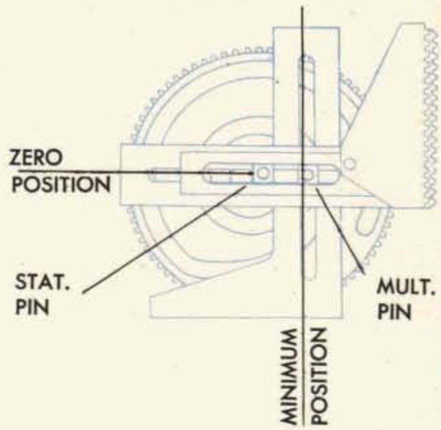
The racks move in the same directions as they did in the rack type multiplier.

The input rack is pinned to an arm which pivots around the stationary pin.



The cam follower pin is fixed to the input slide so that this slide is positioned by the cam.

When the output rack and the pivot arm are parallel, they are in their ZERO positions.



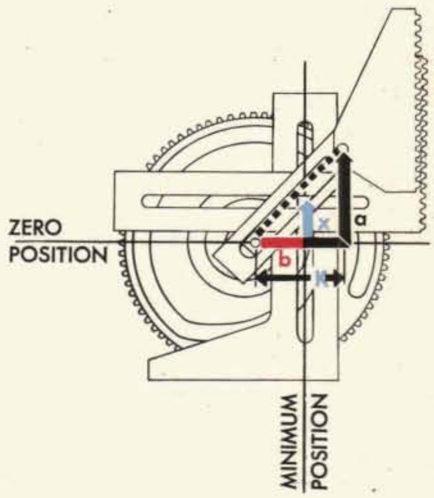
The slide is in its zero position when the multiplier pin is directly over the stationary pin.

In some cam multipliers there is a "minimum" position but no zero position, since the grooves of some of the cams compute functions which do not go to zero. A secant cam is an example.

Suppose both input gears are turned:

1 The cam turns and moves the slide a distance b. Distance b is then the *output of* the cam and the *input* to the multiplier.

2 The input rack moves upwards from its zero position an amount a.



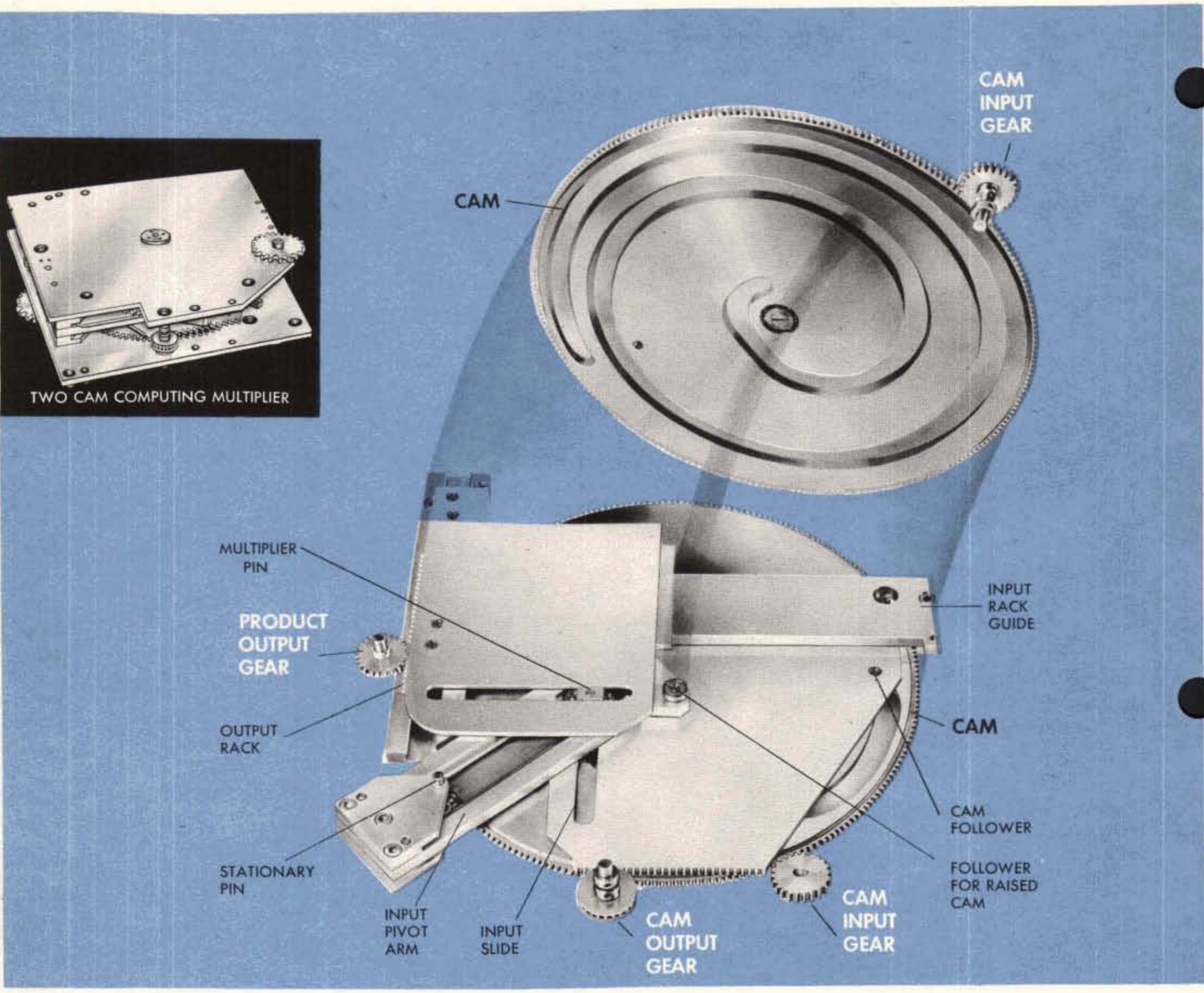
These two inputs make the output rack move up a distance x from zero position.

These distances form two right triangles. These triangles are just the same as those used for the rack or screw type multiplier.

$$\frac{x}{b}=\frac{a}{K} \quad \text{or} \quad x=\frac{ab}{K}$$

Distance K is a constant. Distance b is the cam output.

THE MULTIPLIER OUTPUT, x, IS PROPORTIONAL TO THE OUTPUT OF THE CAM MULTIPLIED BY THE RACK INPUT.



The TWO CAM COMPUTING MULTIPLIER

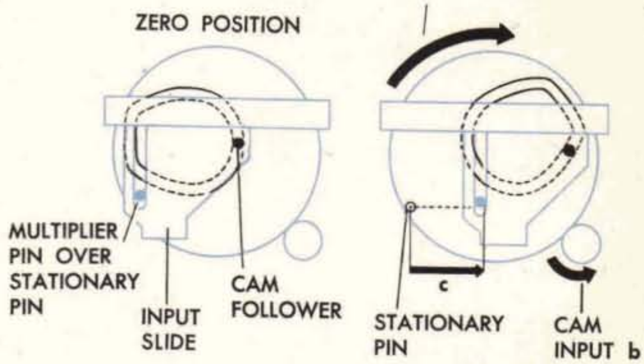
The two-cam multiplier computes a function of each of the two input values, then multiplies one function by the other.

In this multiplier, BOTH input racks are replaced by cams. The cams position the input slide and pivot arm.

The product output value is always the product of the two cam outputs.

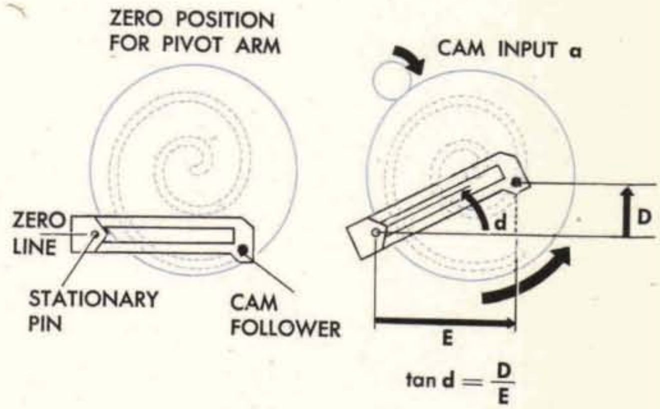
The cam follower in the groove of one cam moves the input slide from side to side. The position of the slide always represents the cam output. The slide can be used to turn a *cam output gear*, and thus make the *cam* output available as another output in addition to the *product* output.

Zero position of the slide is at the left with the multiplier pin over the stationary pin.



The cam follower in the groove of the second arm swings the input pivot arm on the stationary pin.

The second cam is always cut in such a way that the output is the tangent of the angle which the pivot arm forms with the zero line.



The multiplier pin is mounted in the pivot arm, and passes through the input slide and the output rack.

Two triangles are formed, just like the triangles formed in the screw type multiplier.

The tangent of angle d is equal to a function of the cam input a.

$$f(a) = \tan d = \frac{D}{E}$$

Side c of the small triangle is equal to a function of the cam input b.

$$f(b) = c$$

Since the two triangles are similar triangles,

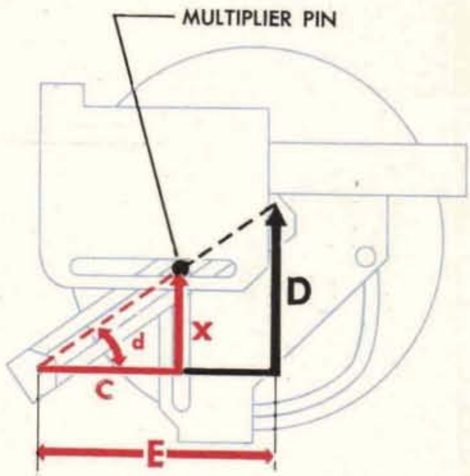
$$\frac{D}{x} = \frac{E}{c}, \qquad \text{or } \frac{D}{E} = \frac{x}{c}$$

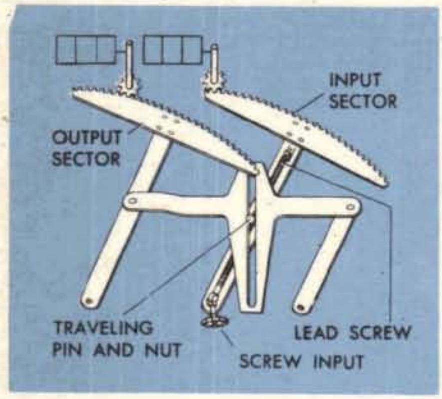
Also, since

$$\frac{D}{E} = f(a), \quad \text{and} \quad c = f(b)$$

$$f(a) = \frac{x}{f(b)}, \quad \text{or } f(a) \times f(b) = x.$$

Each cam output is a function of the cam input and the multiplier's output is the product of these two functions.





Setting the SECTOR TYPE

The parts of the sector type multiplier to be set are:

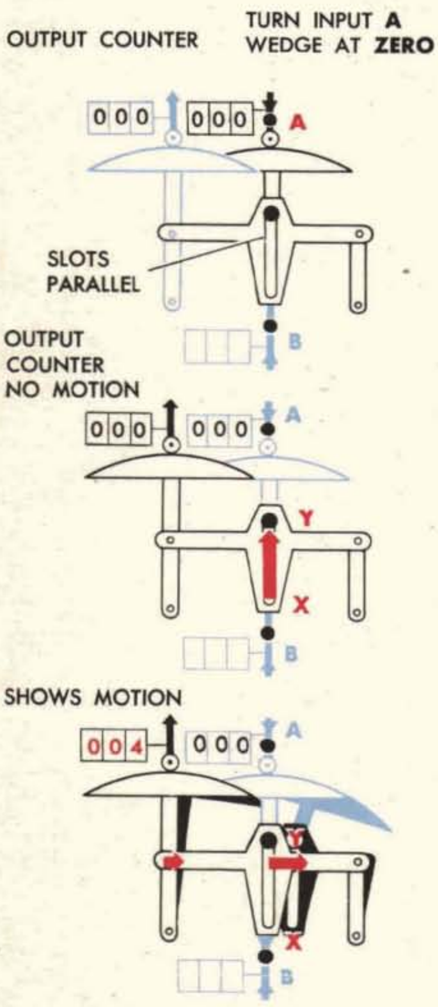
1. The Input Sector
2. The Lead Screw

And the Parts which aid in setting are:

1. The Traveling Nut and Pin
2. The Output Sector

The *INPUTS* go to the Input Sector and the Lead Screw. The *OUTPUT* comes off the Output Sector.

The input shaft *A* positions the Input Sector and also positions the counter. When setting, the purpose is to join the input sector and the counter through the setting clamp so that the position of the sector is exactly indicated by the counter.



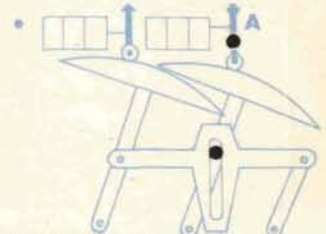
To set the input sector:

1. Turn Input Shaft *A* until counter is at zero. Wedge the Input.
2. Position the Input Sector so that its slot is parallel to the slot in the parallel arm. This is the Zero position for the Input Sector.
3. Slip-tighten the setting clamp.
4. Starting with the Multiplier Pin over the Input Sector pivot pin at *X*, run it to *Y*. Observe the amount of movement of the output counter.
5. Here there is no motion. The Input Sector is set correctly. Since the slots are parallel, the pin can travel along the slots without moving the Output.
6. Here the Input Sector setting is incorrect. The indicator shows the distance the Output Sector moved. This distance represents the amount of error in setting.
7. To correct the error, push the Input Sector, slipping through the setting clamp until the Output indicator returns to its original position.

   Always correct with the pin at point *Y*, because this position will give the maximum movement on the indicator.
8. Repeat 4 and 7 as often as necessary to eliminate the movement of the indicator.
9. Tighten the setting clamp.
10. Remove wedge.

MULTIPLIER

The Input shaft *B* turns the lead screw which positions the multiplier pin. This Input shaft also positions the counter. The purpose, when setting, is to join the pin and the counter so that the position of the pin is exactly indicated by the counter.

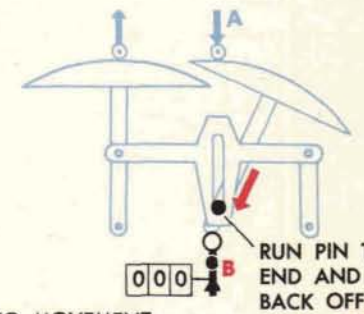


To set the lead screw:

1 Turn the Input shaft *B* until the counter is at Zero. Wedge the Input.

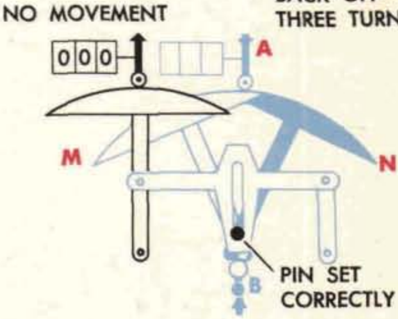
2 Run the pin to the end of the screw near the Input Sector pivot pin, then back off three turns. This is approximately zero for the pin.

3 Slip-tighten the setting clamp.



4 Starting with the input sector at *M* turn input *A* to bring it to *N*. Observe movement of the output indicator.

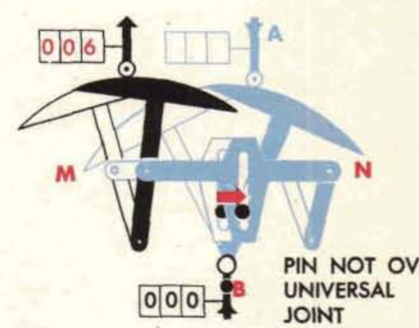
5 Here there is no movement. The lead screw is set correctly. The pin is right over the universal joint in the screw, and motion of the input sector causes no output.



6 Here the lead screw setting is incorrect. The indicator shows the distance that the output sector moved. This distance represents the amount of error in setting.

7 To correct this error, move the pin by slipping the lead screw shaft through the setting clamp. The input shaft *B* should still be wedged. Turn the lead screw shaft until the indicator returns *halfway* to its original reading.

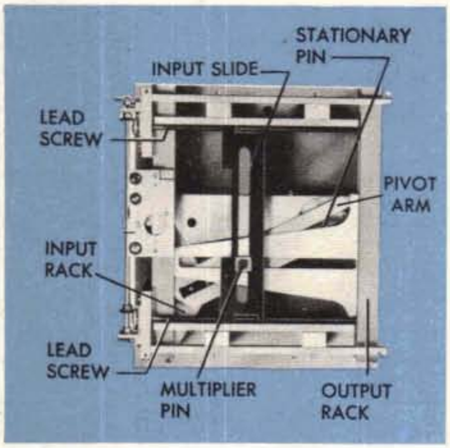
Always correct at *M* or *N* because these positions give the maximum movement on the indicator.



8 Repeat 4 and 7 until there is no movement of the output indicator.

9 Tighten setting clamp. Remove wedge.

Setting the SCREW TYPE



The method of setting the screw type multiplier is very similar to that of the sector type.

The parts to be set are:

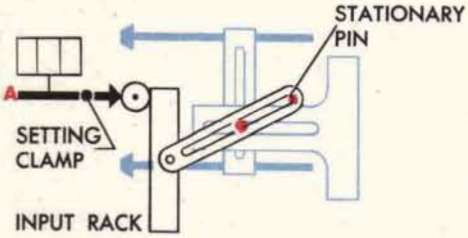
1. The Input rack
2. The Lead screws.

And the parts which aid in setting are:

1. The Input slide
2. The multiplier pin
3. The stationary pin
4. The output rack.

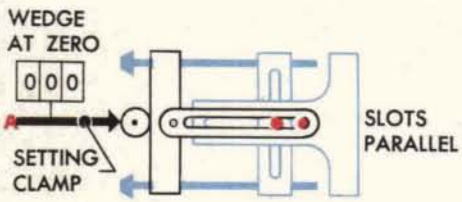
The *INPUTS* go to the Input rack and the Lead screws.

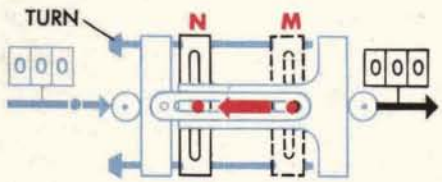
The *OUTPUT* comes off the Output rack.

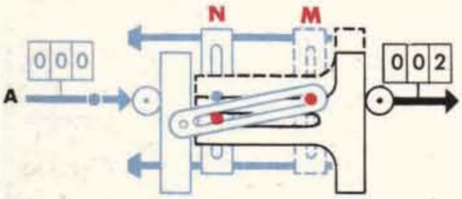


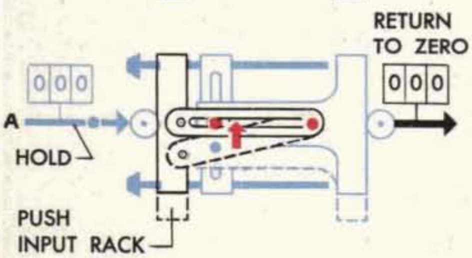
The INPUT shaft *A* positions the Input rack and also positions the counter. The purpose of the setting is to join the Input rack and the counter through the setting clamp so that the position of the Input rack is indicated by the counter.

To set the input rack:





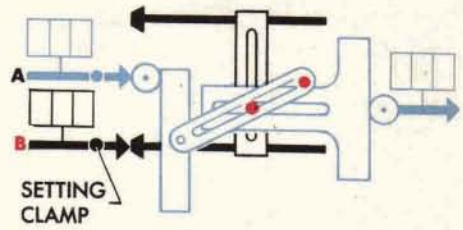




1. Turn Input shaft *A* until the counter is at zero. Wedge the Input.
2. Position the Pivot arm slot of the Input rack so that it is parallel to the Output rack slot. This is approximately zero position for the Input rack.
3. Slip-tighten the setting clamp.
4. Starting with the Input slide at *M* where the multiplier pin is over the stationary pin, run the slide to *N*. Note the movement of the Output indicator.
5. Here the input rack is set correctly. The two slots are parallel and the multiplier pin travels along the pivot arm slot without moving the output rack. There is minimum motion on the output indicator.
6. Here the Input rack setting is incorrect. The slots are not exactly parallel. Moving the Input slide produces an output. The distance the indicator moved represents the amount of error in setting.
7. To correct this error, push the Input rack until the indicator returns to its original position. Always correct with the Input slide at *N* because this position will give the maximum movement of the indicator.
8. Repeat 4 and 7 as often as necessary to reduce the movement of the indicator to minimum.
9. Tighten the setting clamp.
10. Remove wedge.

MULTIPLIER

The Input shaft *B* turns the lead screws which position the Input slide. This Input also positions a counter. When setting, the purpose is to join the lead screw and the counter through the setting clamp so that the position of the slide is exactly indicated by the counter.

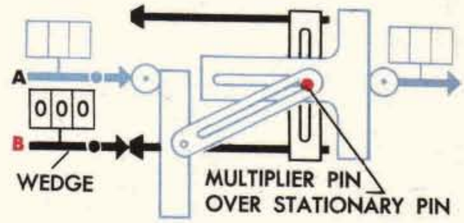


To set the lead screw:

1 Turn Input shaft *B* until the counter reading is zero. Wedge the Input.

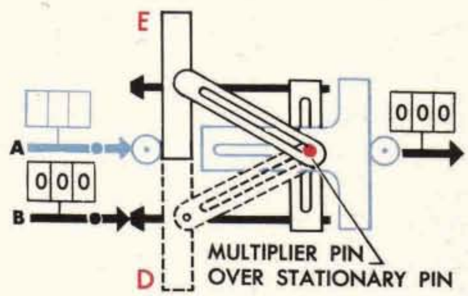
2 Run the Input slide to the point where the multiplier pin is directly over the stationary pin. This is the approximate zero position of the Input slide.

3 Slip-tighten the setting clamp.

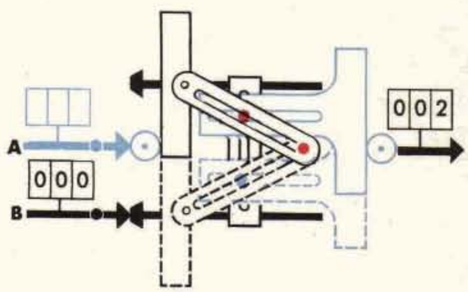


4 Starting with the Input rack at *D*, run it to *E*. Note amount of movement of the output indicator.

5 Here the lead screw is set correctly. Because the multiplier pin in the Input slide is directly over the stationary pin, the Input rack can move without moving the output rack. There is minimum motion on the output indicator.



6 This setting of the lead screw is incorrect. The multiplier pin is not exactly lined up over the stationary pin, so that moving the Input rack causes an output. The distance the indicator moved represents the amount of error in setting.

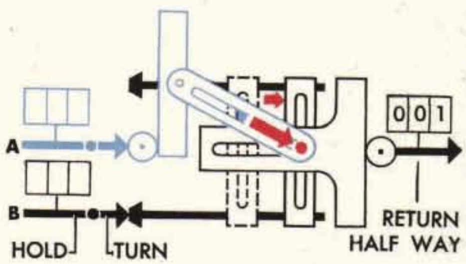


7 To correct the error, move the Input slide by slipping through the setting clamp until the indicator returns *half-way* to its original position.

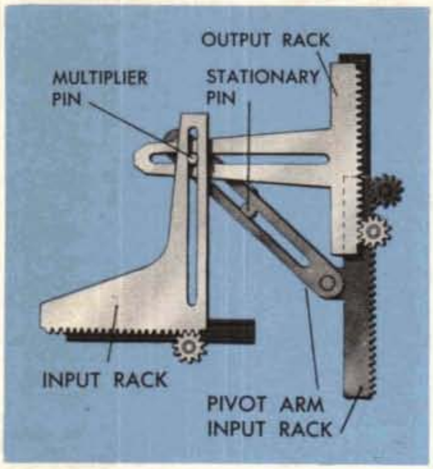
Always correct at *E* or *D* because these are the maximum positions.

8 Repeat 4 and 7 until there is minimum movement.

9 Tighten the setting clamp. Remove wedge.



Setting the RACK TYPE



The Parts of the Rack Type Multiplier to be set are:

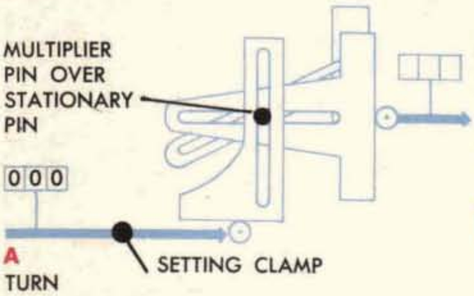
1. The Input Rack
2. The Pivot Arm Input Rack

and the parts which aid in setting are:

1. The Multiplier Pin
2. The Stationary Pin
3. The Output Rack

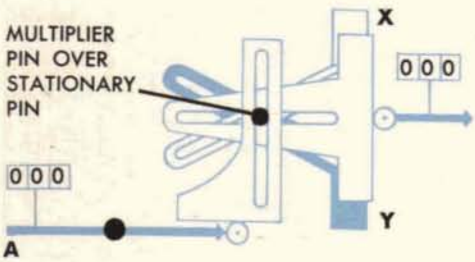
The *Inputs* go to the Input rack and the Pivot Arm Input Rack.

The *Output* comes off the Output Rack.

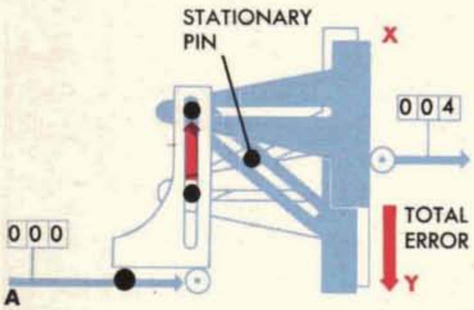


The input shaft *A* positions the input rack and also positions the counter. The purpose of the setting is to join the input rack and the counter through the setting clamp so that the position of the input rack is indicated by the counter.

To set the input rack:

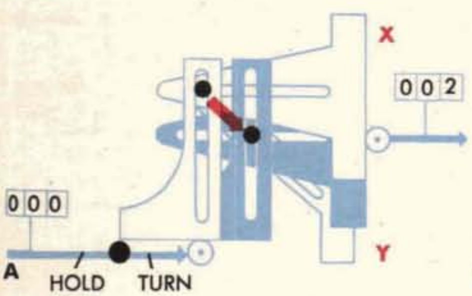


1. Turn the input shaft *A* until the counter is at zero. Wedge the input.
2. Position the input rack so that the multiplier pin is directly over the stationary pin. This is the approximate zero position of the input rack.
3. Slip-tighten the setting clamp.
4. Starting with the pivot arm input rack at *X*, run it to *Y*. Note the motion of the output rack indicator.
5. Here the input rack setting is correct, because the multiplier pin is directly over the stationary pin and movement of the pivot arm rack causes no motion on the output indicator.



6. Here the input rack setting is incorrect. The pins are not lined up, so when the pivot arm rack is moved there is an output. The distance the indicator moves represents the amount of error in the setting.
7. To correct the error, push the input rack until the indicator returns halfway to its original position.

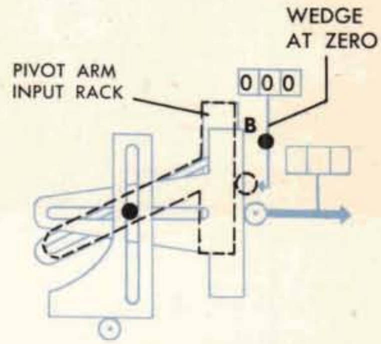
   Always correct with pivot arm input rack at *X* or *Y* because these positions will give the maximum movement on the indicator.



8. Refine the setting until the error is minimum and evenly split.
9. Tighten the setting clamp.
10. Remove wedge.

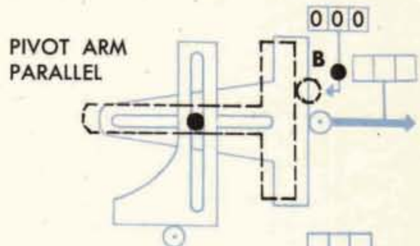
MULTIPLIER

The input shaft *B* moves the pivot arm input rack. This input also positions the counter. When setting, the purpose is to join the rack and the counter through the setting clamp so that the position of the rack is exactly indicated by the counter.

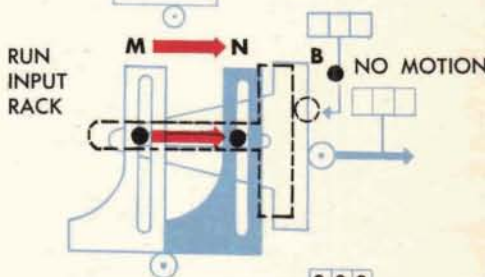


To set the pivot arm input rack:

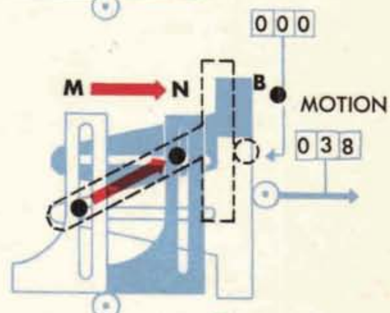
1. Turn input shaft *B* until the counter is at zero reading. Wedge the input.
2. Position the pivot arm input rack so that its slot is parallel to the slot in the output rack.
3. Slip-tighten the setting clamp.
4. Starting with the input rack at *M* turn *INPUT A* and run it to *N*. Note the motion of the output indicator.



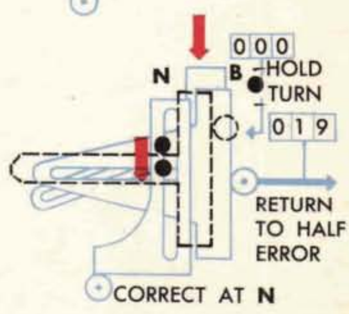
5. Here the Pivot-Arm Input Rack setting is correct. The slots are parallel and movement of the Input Rack causes zero or minimum motion on the output indicator.



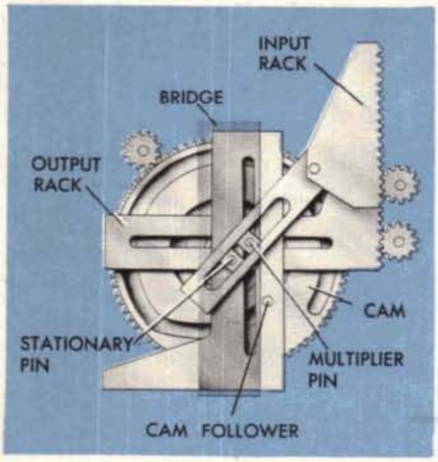
6. Here the setting of the Pivot Arm Input Rack is incorrect. The slot of the Pivot Arm Input Rack is not exactly parallel, so that when the input rack is moved there is an output. The distance the indicator moves represents the amount of error.

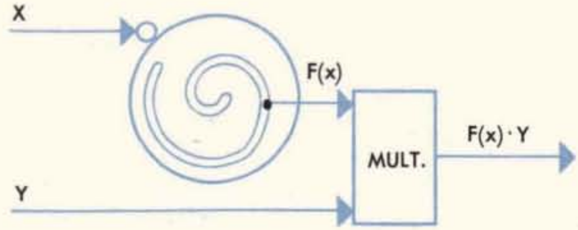


7. To correct this error, push the pivot arm input rack through the clamp until the indicator returns halfway to its original position.
8. Refine the setting until the error is minimum and evenly split.
9. Tighten setting clamp.
10. Remove wedge.



Setting the SINGLE CAM





The single Cam Type Multiplier is a combination of a Rack Type Multiplier and a Cam.

Notice here that one *input* to the multiplier is the *output* from the cam.

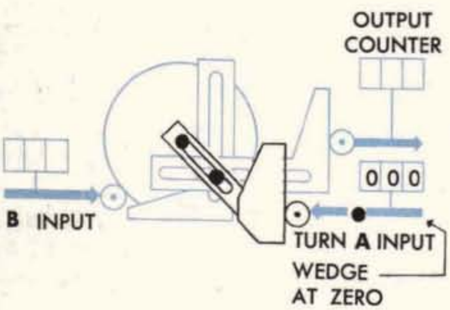
The parts to be set are:
1. The Input Rack
2. The Cam

And the parts which aid in setting are:
1. The Multiplier Pin
2. The Stationary Pin
3. The Output Rack

The *INPUTS* go to the input rack and the cam.

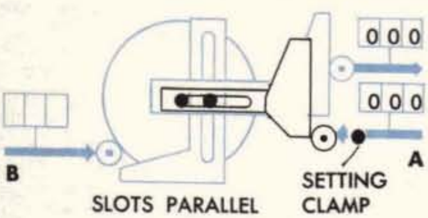
The *OUTPUT* comes off the Output Rack.

Input *A* positions the input rack and also positions a counter. The purpose of the setting is to join the input rack and the counter through the setting clamp so that the position of the input rack is indicated by the counter.

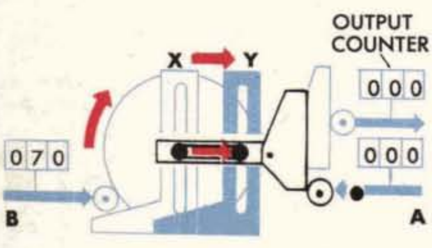


To set the input rack:

1. Turn the input shaft *A* until the counter is at zero. Wedge the input.



2. Position the input rack so that its slot is parallel to the output rack slot. This is the approximate zero position of the input rack.
3. Put the output counter on zero.
4. Slip-tighten the setting clamp.



5. Starting with the pin at *X*, where the multiplier pin is at its minimum position, turn the input *B* and run the pin to *Y*. Note movement of the output counter.
6. Here the input rack is set correctly. The two slots are parallel and the pin can travel along its groove without moving the output rack. There is minimum or no motion on the output counter.

COMPUTING MULTIPLIER

7 Here the input rack is set incorrectly. The slot in the input rack is not exactly parallel with the output rack, so that moving the pin causes an output. The change of output counter reading represents the amount of error in setting.

8 To correct this error push the input rack through the setting clamp until the output counter returns to its original position. Always correct at *Y* because this position will give the maximum movement on the output counter.

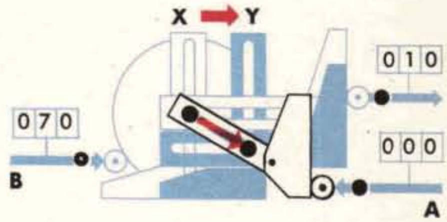
9 Refine the setting until there is minimum or no motion of the output counter.

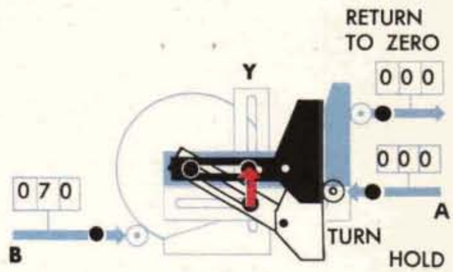
10 With input A counter at 0 and output counter at 0 tighten the setting clamps.

11 Remove the wedge.

Input *B* turns the cam which positions the multiplier pin. This input also positions a counter.

When setting, the purpose is to join the cam and the counter through the setting clamp so that the position of the cam is exactly indicated by the counter.





To set the cam:

1 Position the input rack at *V*. Wedge the input. This is a maximum position. The counter reading, *V*, is given in each Computer's setting notes.

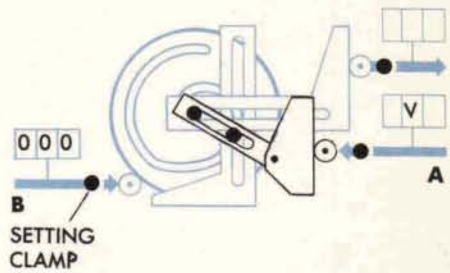
Assume that with a cam input of 60 and with the input rack at position *V* the output will be 135.

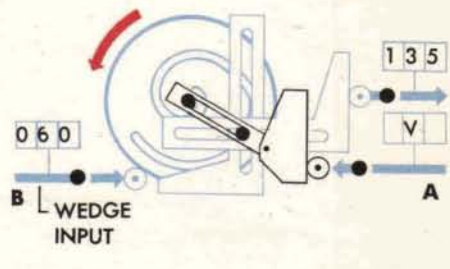
2 Now turn input *B* until the input counter reads 60 and wedge the input.

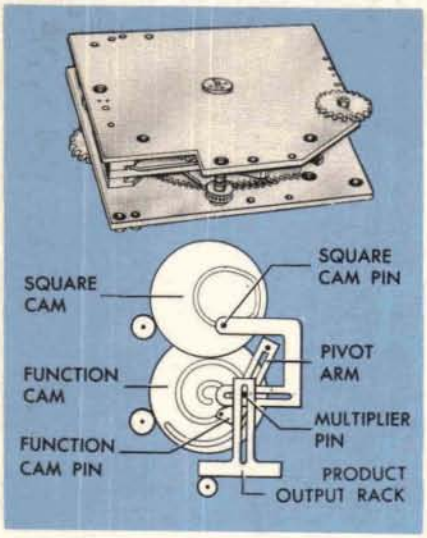
3 Turn the cam until the output counter has the correct output reading 135 for the given input reading 60.

NOTE: The Computer's setting notes give the output reading for the input value to be used as the setting position.

4 Tighten the setting clamp. Remove the wedges.







Setting the TWO CAM

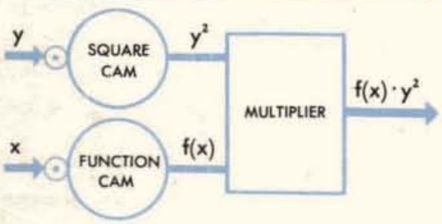
The double cam multiplier is a combination of a rack type multiplier and two cams. Usually one of these is a square cam, and the other a function cam.

The parts to be set are:

1. The Square Cam
2. The Function Cam
3. The Output Counter

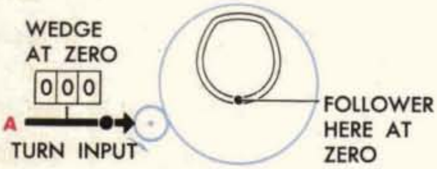
The parts which aid in setting are:

1. The Function Cam Pin
2. The Square Cam Pin
3. The Output Rack
4. The Pivot Arm



Inputs go to the square cam and the function cam. Outputs come off two racks, but only the output which gives the *product* of the cam outputs is used in setting.

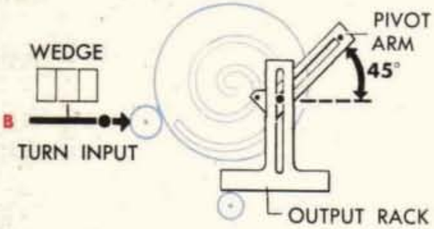
The square cam is positioned by input *A* which also positions the counter. In setting, the purpose is to join the square cam and the counter through the setting clamp so that the position of the square cam is exactly indicated by the counter. The method consists of turning the square cam input exactly the same amount above zero and below zero, and adjusting the setting clamp until the cam gives the same positive output for each of these two inputs.



Setting the square cam

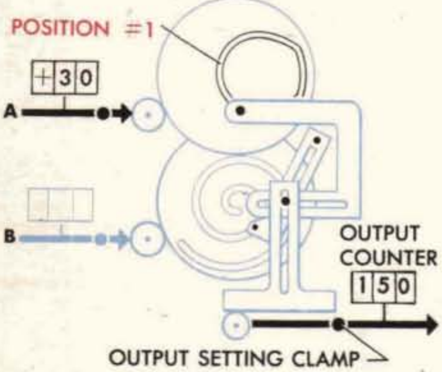
1. Turn the input *A* until the counter setting is zero. Wedge the input.
2. Position the square cam at its estimated zero position.
3. Slip-tighten the setting clamp. Remove the wedge. The cam is now approximately set to the counter.
4. Position the function cam so that the pivot arm is at approximately its maximum position which is near the center.

   At this position of the cam the pivot arm is at a 45° angle to the output rack, so any motion of the square cam follower will cause maximum motion of the output rack.
5. Put the output rack counter on zero.
6. Slip-tighten the output clamp.
7. To check how closely the square cam was set at the zero position, set up a table like this:



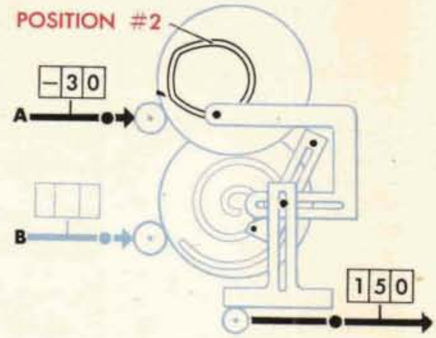
	SQUARE CAM INPUT COUNTER READING	OUTPUT COUNTER READING
POSITION #1	**plus 30**	**output #1**
ZERO	**0**	**0**
POSITION #2	**minus 30**	**output #2**

8. Turn input *A* to run the square cam to Position #1 (exactly plus 30 in this example).
9. Record the reading of the output counter.



COMPUTING MULTIPLIER

10 Now turn input *A* to run the square cam to Position #2 (exactly minus 30 in this example).

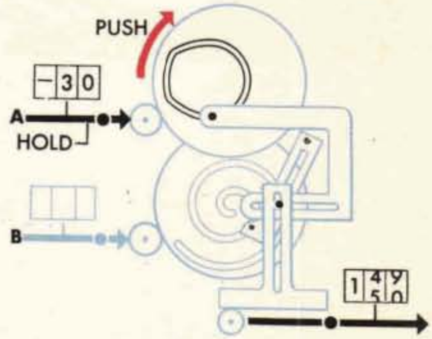


11 Record the reading of the output counter. If the setting is correct, output #1 will equal output #2.

12 Here the square cam is set correctly:

POSITION #1	**plus 30**	**plus 150**
ZERO	**0**	**0**
POSITION #2	**minus 30**	**plus 150**

13 Here the setting is incorrect; the readings do not agree.



POSITION #1	**plus 30**	**plus 125**
ZERO	**0**	**0**
POSITION #2	**minus 30**	**plus 175**

14 To correct, first find the average output counter reading. To do this add output #1 and output #2, and divide by 2:

Output #1 125
Output #2 175

$$\overline{300} \div 2 = 150$$

15 Then with the square cam input counter held at its reading for either Position #1 or Position #2, slip the square cam until the output counter is at the average reading.

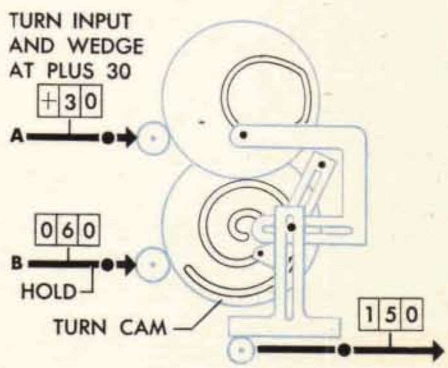
16 Return the input counter to zero by turning input *A* and reset the output counter on zero.

17 Repeat until equal output readings are obtained.

18 Tighten the setting clamp.

Setting the function cam

NOTE: These readings are samples. The actual values are given in each Computer's setting notes.



1 Turn input *A* to bring the square cam to Position #1 (plus 30). Wedge input *A*.

2 Put input *B* counter on 60. Wedge the counter.

3 Turn the function cam until the output counter reading is 150. The cam follower is near the inner radius of the cam.

4 Tighten the setting clamp.

5 Remove the wedges.

COMPONENT SOLVERS

To solve a fire control problem, it is not enough to know the speed and direction of own ship, the target, the wind, and other variables.

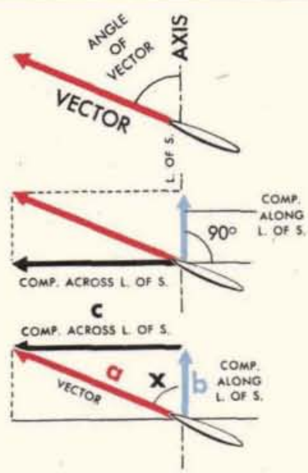
These velocities must be broken down into their COMPONENTS along and across the line of sight.

Finding the components of velocities is a simple enough mathematical job, but it takes too much time to do it with pencil and paper under combat conditions.

Component solvers break down these velocities or other variables, giving their components instantly, accurately, and continuously.

Remember?

A velocity vector looks like this. It is an arrow that represents a speed in a certain direction. The length of the arrow represents speed. The angle between the arrow and a reference axis represents direction.



In fire control this axis is usually the line of sight. The components of the vector are represented by two arrows: one along the axis, and the other at right angles to the axis.

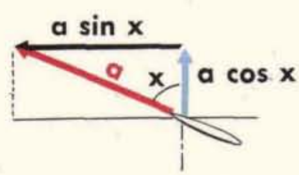
By drawing the component across the line of sight in this position, the vector and two components make a right triangle. This is the way components are usually shown.

The values of the two components are easily figured from this triangle.

$$\text{Cos } X = \frac{b}{a} \qquad b = a \text{ Cos } X$$

So the component *along the line of sight* will always have the value of the vector *times the cosine of the vector angle.*

$$\text{Sin } X = \frac{c}{a} \qquad c = a \text{ Sin } X$$

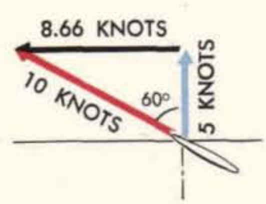


So the component *across the line of sight* will always have the value of the *vector times the sine of the vector angle.*

Here's an example: A ship is traveling at 10 knots at 60° to the line of sight.

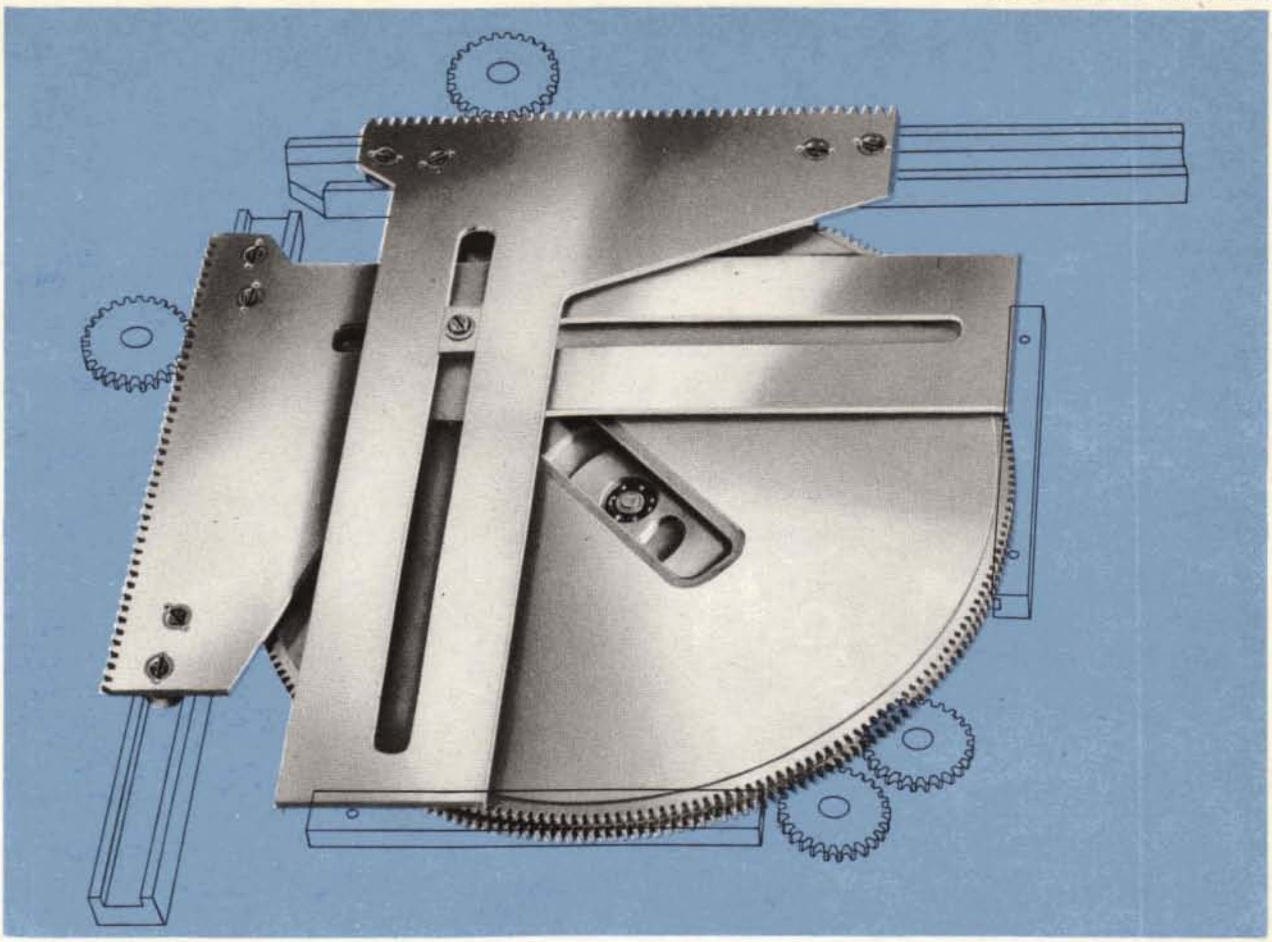
The cosine of 60° is .5. The sine of 60° is .866.

The component along the line of sight = 10 knots × .5 = 5 knots. The component across the line of sight = 10 knots × .866 = 8.66 knots.



SO THE SPEED OF 10 KNOTS AT 60° HAS THE SAME EFFECT AS SIMULTANEOUS SPEEDS OF 5 KNOTS ALONG THE LINE OF SIGHT AND 8.66 KNOTS ACROSS IT.

There are other kinds of vectors besides velocity vectors. A distance in a given direction is a vector, and can be broken down into components exactly like a velocity.



This is a CAM TYPE COMPONENT SOLVER

Cam type solvers are used to resolve many different vectors in the fire control problem.

The own ship component solver is typical.

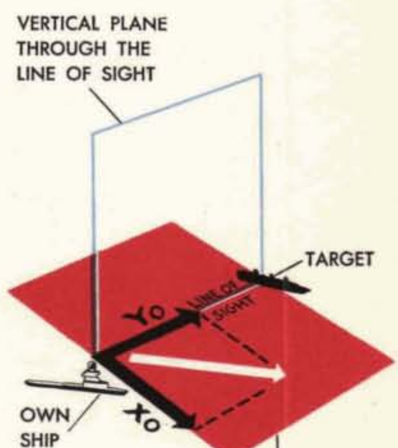
It breaks down own ship speed along her course into:

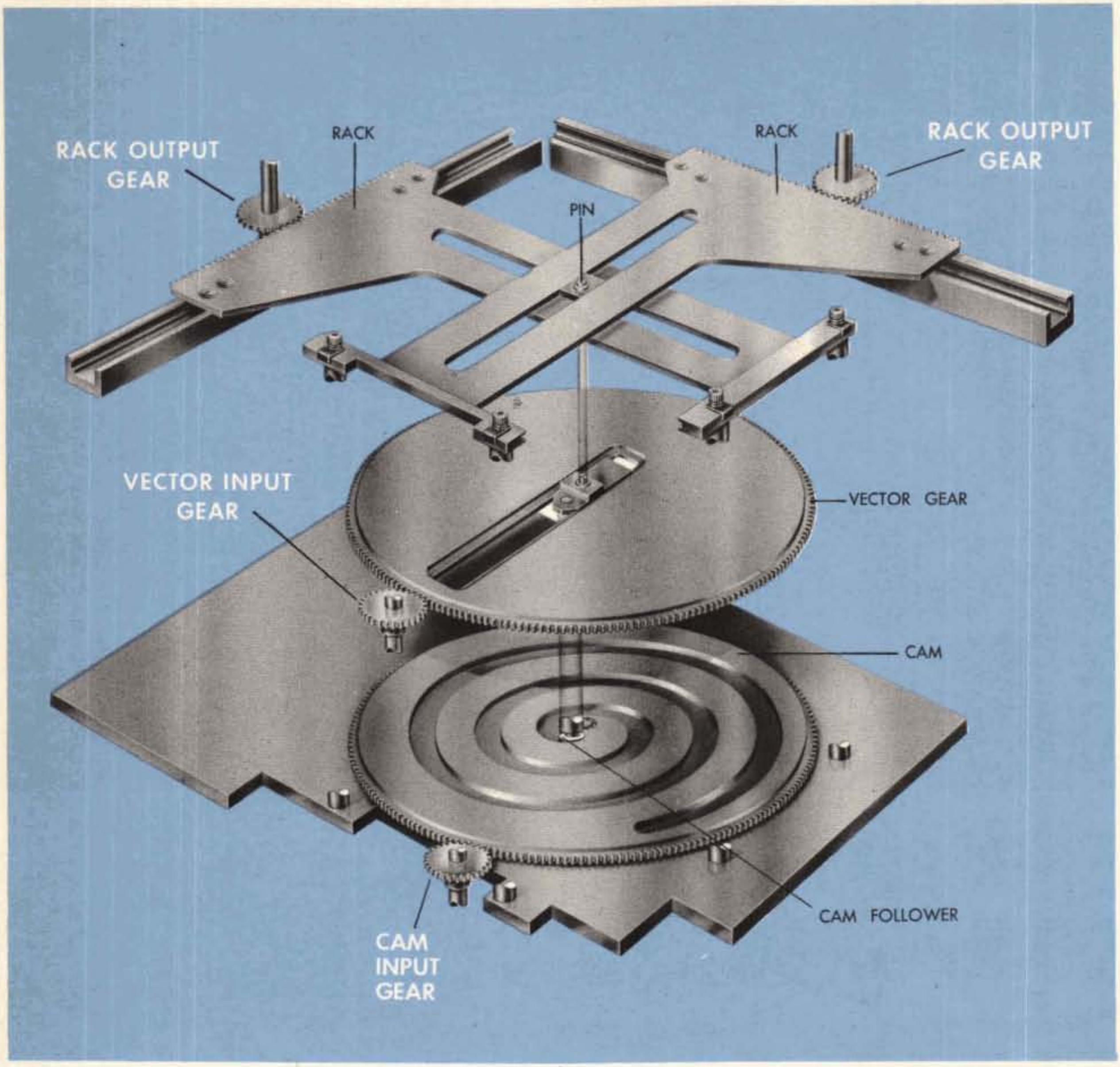
1 The speed at which she is moving on a line straight toward the target—along the line of sight. (More accurately, the horizontal component of own ship velocity in vertical plane containing the line of sight, *Yo*.)

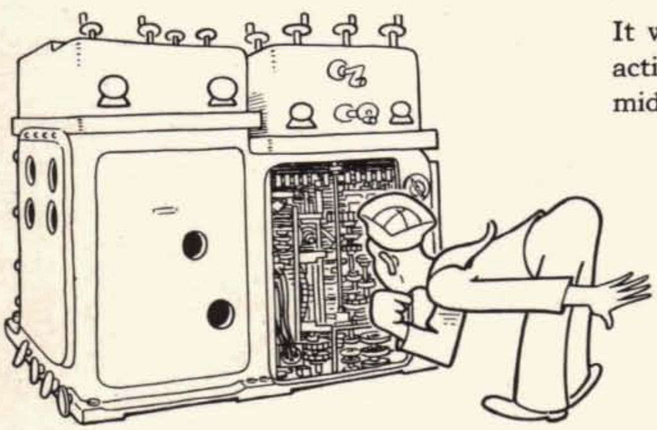
2 The speed at which she is moving at right angles to the line of sight. (More accurately, the horizontal component of own ship velocity at right angles to the line of sight, *Xo*.)

The ship's speeds in these two directions are called the COMPONENTS of her actual speed along her course.

Her actual speed along her course is the VECTOR which the ship's component solver resolves.







It will be difficult to see a component solver in action because most of them are buried in the middle of a lot of other mechanisms and gears.

Take a look inside the solver

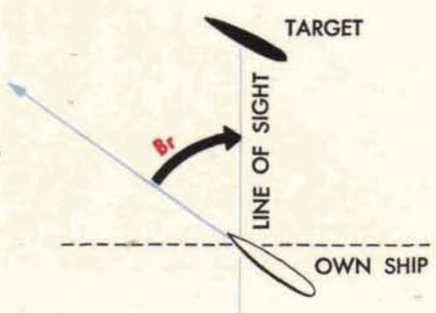
The ship component solver has five main parts:

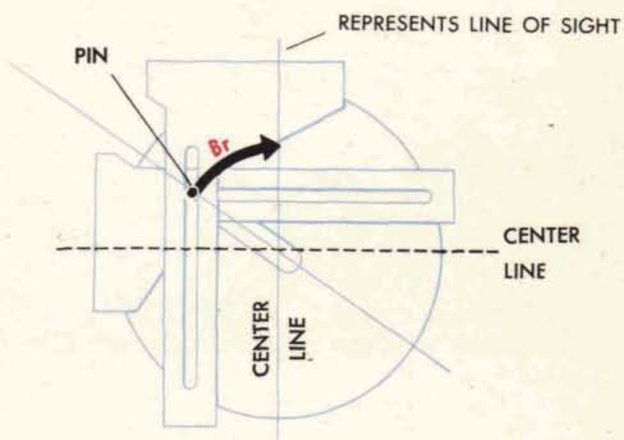
a cam
a vector gear
a pin and follower
two racks

The cam generally has a "constant lead" spiral groove. It is called the speed gear because it is turned amounts corresponding to changes in speed of the ship. It turns in one direction when the ship is picking up speed, and in the opposite direction when the ship slows down.

The vector gear has a straight slot, passing through its center. The vector gear is turned by its input gear in such a way that:

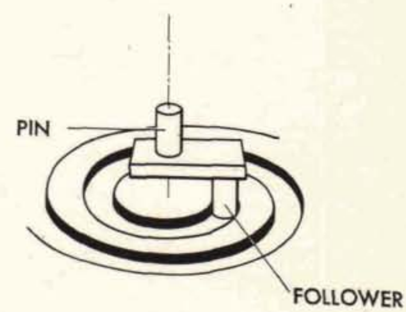
The angle between one center line of the component solver and the slot in the vector gear is always equal to the angle between the fore and aft axis of own ship and the line of sight, measured clockwise from the bow. This angle is called *Br*, relative target bearing in the horizontal plane.





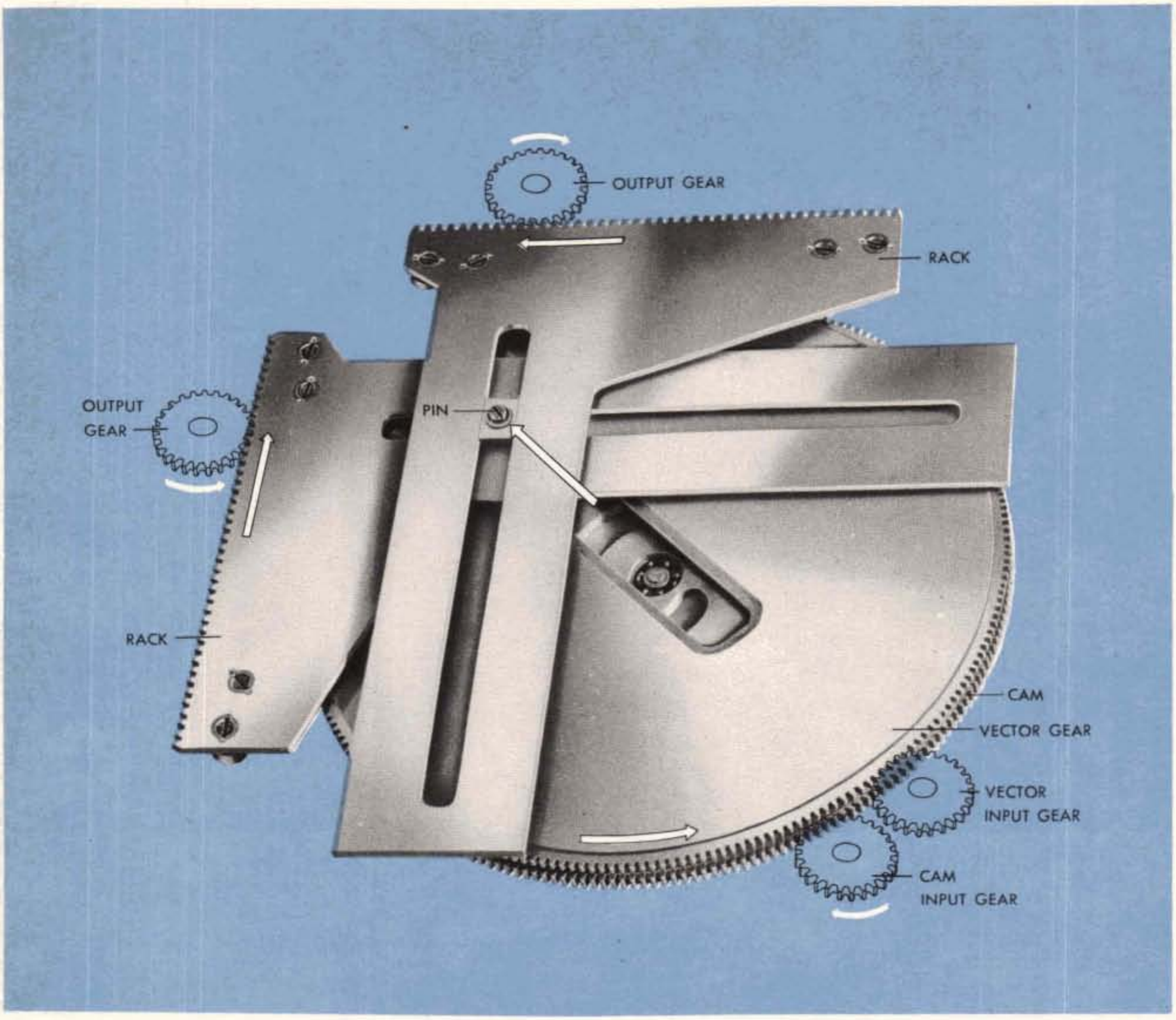
The vector slot represents the fore and aft axis of own ship. One of the center lines represents the line of sight.

The pin is joined to a block which also carries the cam follower. The follower is offset a little from the pin so that the pin is over the center of the cam when the follower is near the inner end of the cam groove.



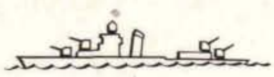
The follower rides in the cam groove and the pin comes up through the slot in the vector gear, so the pin is moved by both the cam and the vector gear, radially by the cam, and angularly by the vector gear.

The two racks are pushed back and forth along their guides by the pin. This movement in turn rotates the two output gears which deliver the components to other mechanisms.



A quick run through the actions

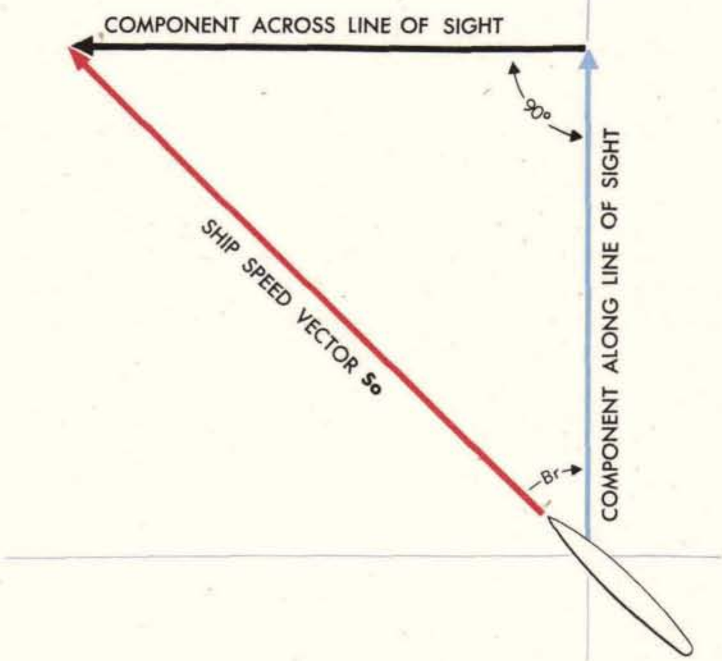
The input gears turn the cam and vector gear.
The cam and the vector gear move the pin.
The pin pushes the racks into position.
The racks turn the output gears.



Knowing how the solver's parts move, the next step is to find out what all this has to do with speed vectors.

Before the mechanism can start to solve any components there must be a vector. The vector is going to be the speed of own ship along its course in relation to the line of sight. The component solver's work can be divided into two parts:

A It must set up a vector of the ship's motion.
B It must solve the components of that vector.

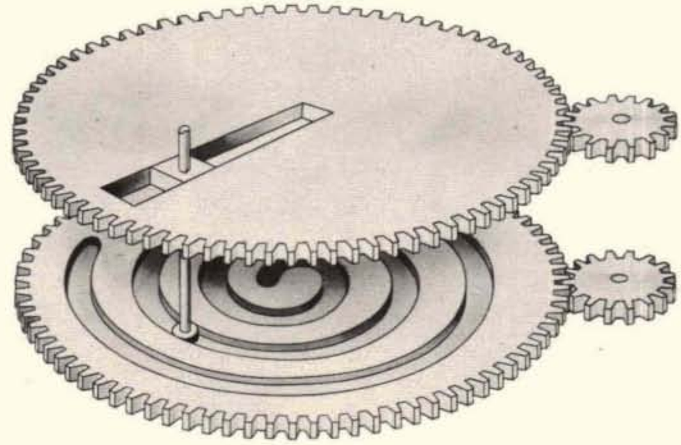


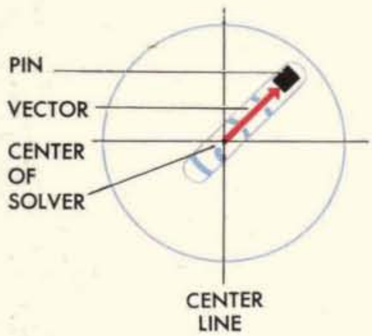
The two components needed are:

1 Speed along the line of sight for range changes.
2 Speed across the line of sight for deflection changes.

These linear motion components are used by other mechanisms which compute deflection prediction and range prediction.

How the VECTOR

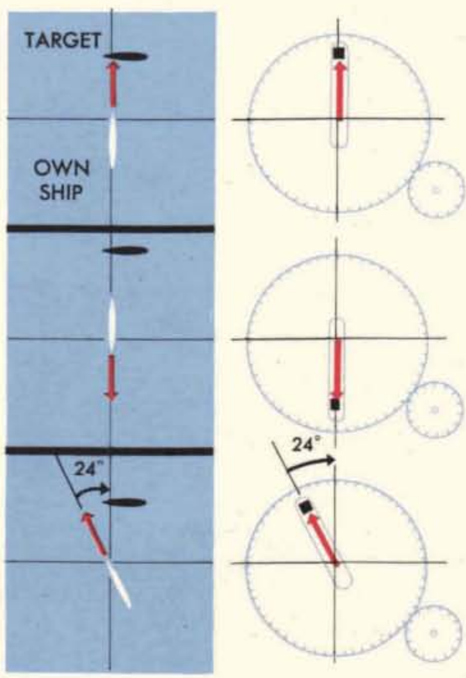




Just this much of the mechanism—the cam, the vector gear, and the pin—establish the vector.

THE VECTOR WILL BE THE LINE FROM THE CENTER OF THE SOLVER TO THE PIN.

The direction of the vector is controlled by the vector gear. The vector gear input turns the vector gear so that the angle between its slot and the center line of the solver corresponds to the angle between the fore and aft axis of own ship and the line of sight.



Here the ship is approaching the enemy right along the line of sight. The slot is along the center line of the solver.

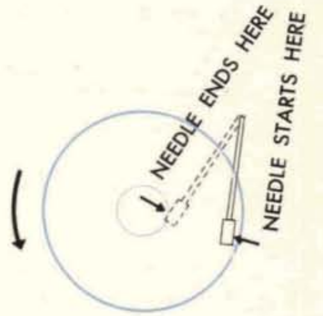
Here the ship's course is still along the line of sight but the ship is moving *away* from the target.

In this case the ship's axis is at 24° to the line of sight. The slot repeats this angle with the center line.

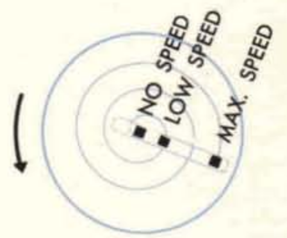
is set up

The *length of the vector* is put into the solver by the speed cam.

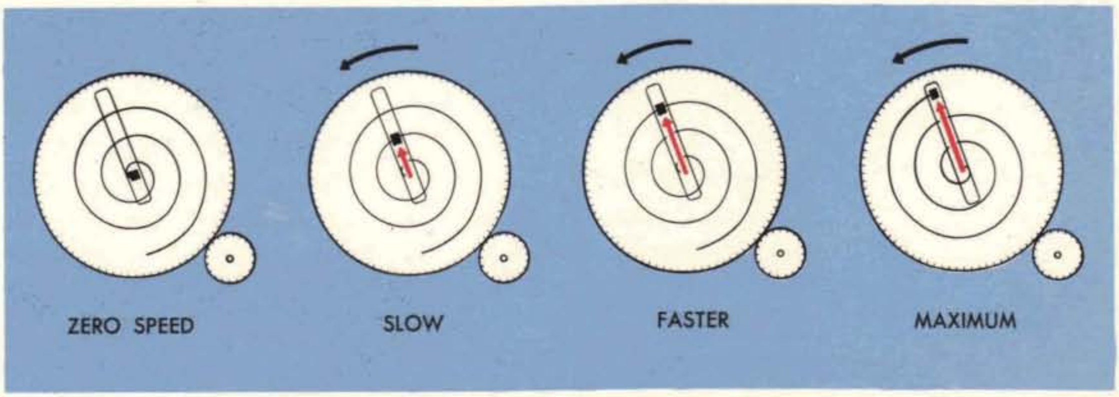
The spiral in the speed cam works like the groove in a phonograph record. As the record turns, the phonograph needle in the groove travels toward the center of the record.



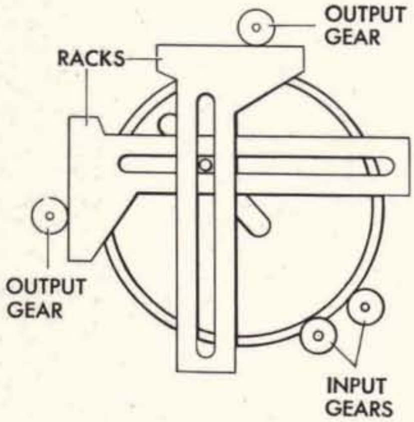
The pin does the same. It moves back and forth in the slot in the vector gear when the speed cam is turned, so that for every speed of the ship there is a definite position of the pin.



This sets up the length of the vector.



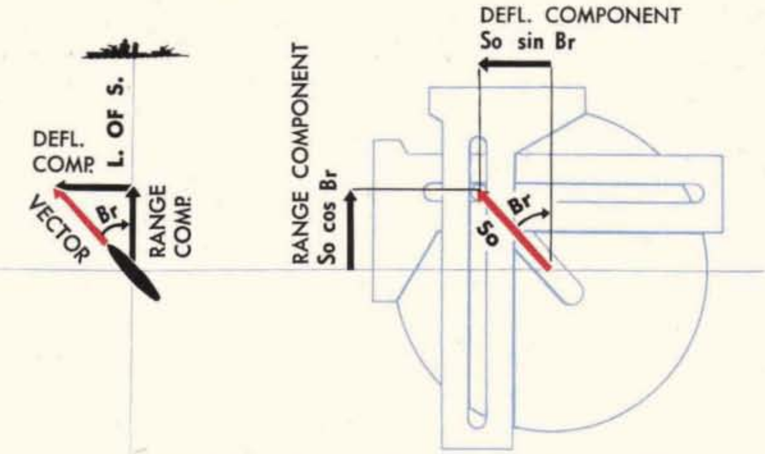
How the components



Up to this point the cam, the vector gear, and the pin have done all the work. Now the output racks come into the picture.

The pin comes up through the slots in the racks, so that every time the pin is moved it will push the racks to new positions. The positions of the racks tell the length of the components.

THE COMPONENTS OF THE VECTOR ARE THE DISTANCES FROM THE CENTER LINES OF THE COMPONENT SOLVER TO THE SLOTS IN THE RACKS.



One rack moves up and down, giving the value of the component along the line of sight, called the RANGE RATE COMPONENT, Yo.

This component will have the value of the speed, So, multiplied by the cosine of Br. (So Cos Br.)

The second rack moves from side to side, giving the components across the line of sight, called the DEFLECTION RATE COMPONENT, Xo.

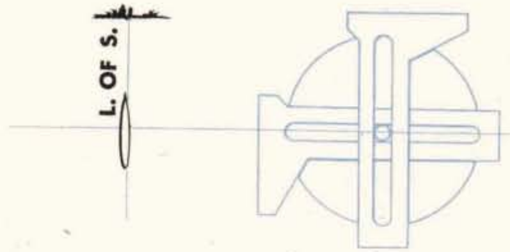
The deflection rate component will equal the speed times the sine of Br. (So Sin Br.)

Every time the rack moves it turns its output gear a proportionate amount. This turning of the output gears positions the output shafts. The positions of these shafts at any moment transmit to other mechanisms the values of the components of ship speed.

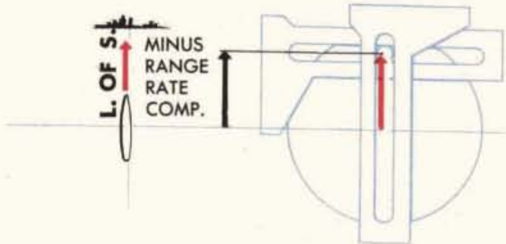
As both racks can move on either side of their center or zero position, both plus and minus values can be obtained.

are SOLVED

Here the ship is not moving at all. The solver is in zero position. The pin is at the center. Both racks lie across the CENTER of the vector gear. Both outputs are zero.



Here the ship is going straight towards the target, so that the range rate component is minus and equal to the whole vector.



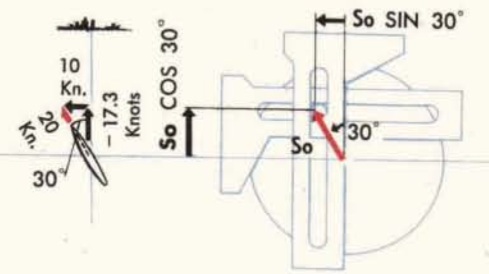
Here the ship is moving at 30° to the line of sight. Its speed is 20 knots.

Sin 30° = .5, Cos 30° = .866

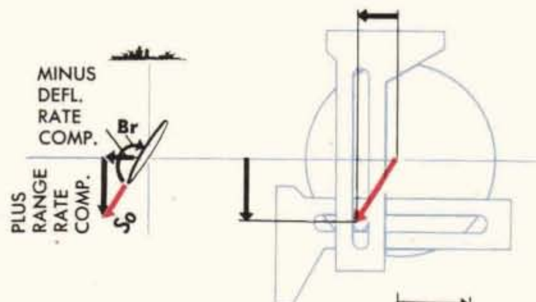
The values of the components are:

Range rate component 20 knots × .866 = 17.3 knots along the line of sight.

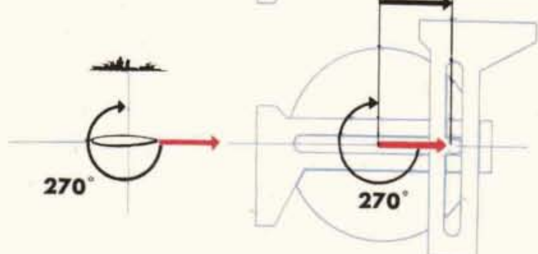
Deflection rate component 20 knots × .5 = 10 knots across the line of sight.



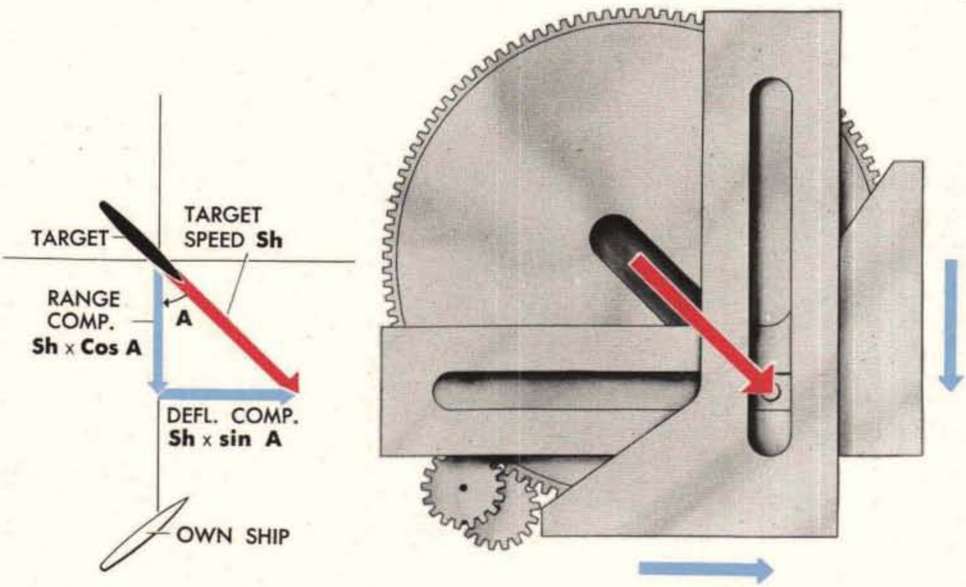
In this example own ship is moving away from the target at 150°. The vector is long, corresponding to 45 knots.



Here the ship moves with a speed of 45 knots across the line of sight, at 270°. The deflection rate component equals the whole vector and is plus. The range rate component is zero.



A cam type solver is also used as the TARGET component solver



The target vector must also be broken down into components along and across the line of sight.

Another cam type solver is used, which is like the ship's solver but often larger.

The vector in this case is target speed and direction. The input to the cam will be Target Speed, *Sh,* horizontally with respect to the earth. The input to the vector gear will be Target Angle, *A,* the angle between the target's direction and the line of sight.

The value of the range component will be: $Sh \times \text{Cos } A$.

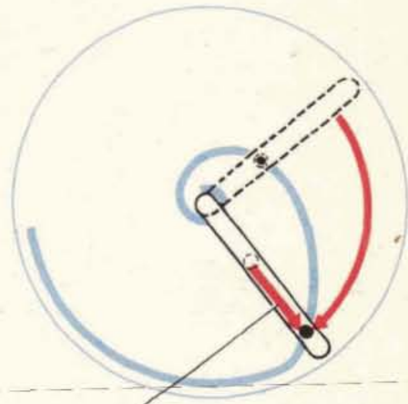
The value of the deflection component will be: $Sh \times \text{Sin } A$.

Why the vector gear input must also go to the cam

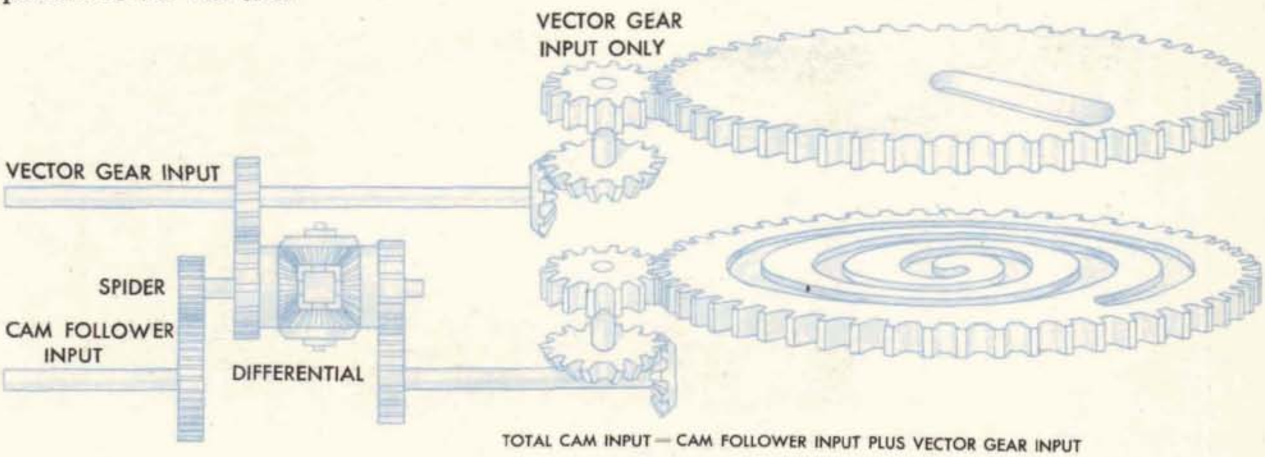
So far, the inputs to the speed cam and to the vector gear have been treated as if they were independent of each other.

Actually they are not.

If the vector gear should turn while the cam was held stationary, the vector slot would move the pin along the cam groove and disturb its position. *This would give a false value for the length of the vector.*



Such errors are prevented by a differential in the cam input line. The vector gear input is meshed with one input of the differential; the cam follower input is meshed with the spider. The output of the differential is geared to the cam. This differential is called a "compensating" differential. Every component solver has one.



TOTAL CAM INPUT — CAM FOLLOWER INPUT PLUS VECTOR GEAR INPUT

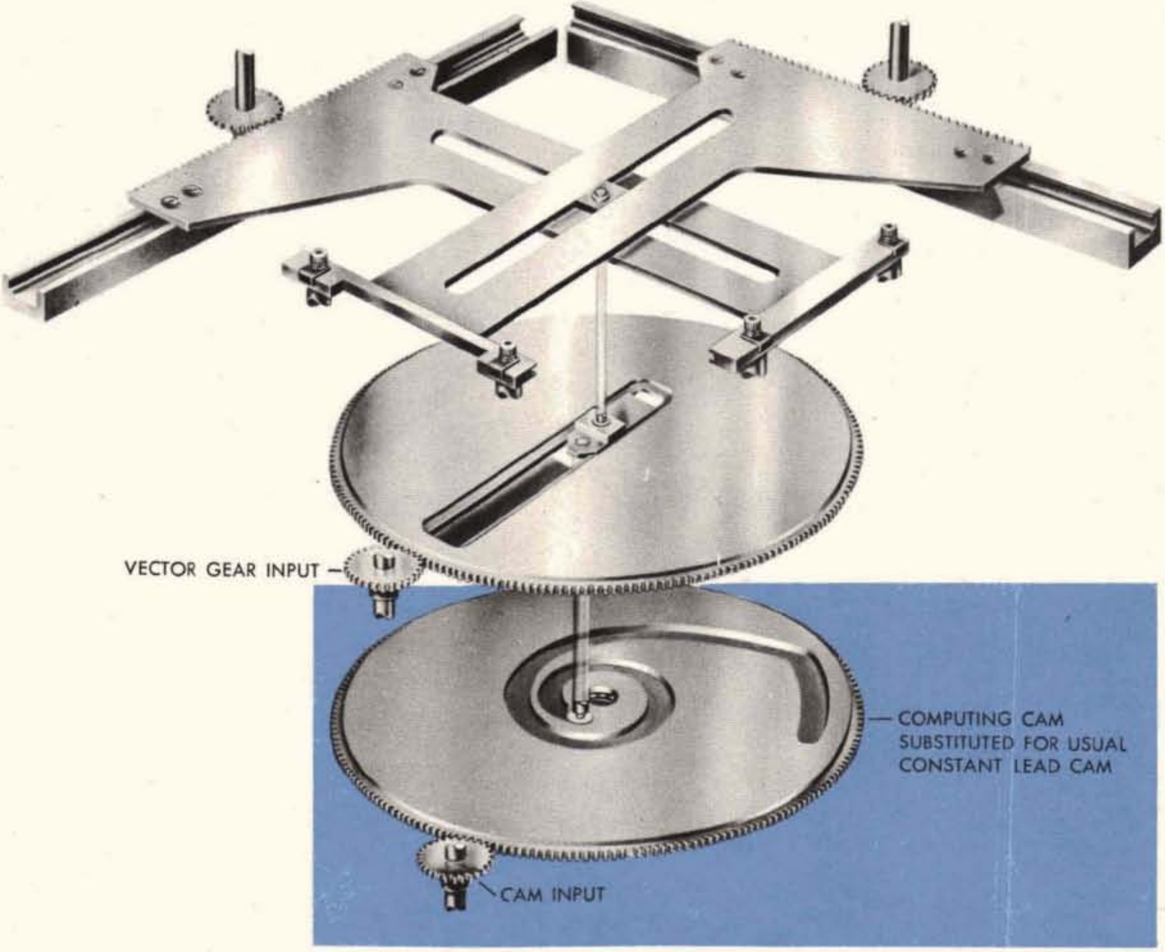
If there is no motion of the cam follower input, the spider is held stationary, and the vector input drives through the differential to turn the cam equally with the vector gear. This prevents the vector slot from pushing the cam follower along the cam groove.

If there is no motion of the vector input, the cam follower input drives through the spider of the differential to turn the cam without disturbing the vector gear.

THE VECTOR GEAR IS TURNED ONLY BY VECTOR INPUTS.

THE CAM IS TURNED BY CAM FOLLOWER INPUTS PLUS VECTOR INPUTS. IN THIS WAY THE VECTOR GEAR CAN BE TURNED WITHOUT DISTURBING THE VALUE REPRESENTED BY THE PIN.

Component solvers sometimes



A component solver's outputs will always be:

The VALUE set in by the CAM times the sine or cosine of the angle set in on the vector gear.

The cam always controls the length of the vector.

Sometimes this vector length is a value which itself must be figured on a computing cam.

THEN INSTEAD OF HAVING THE OUTPUT FROM THE COMPUTING CAM FEED INTO A CONSTANT LEAD CAM IN THE COMPONENT SOLVER, THE COMPUTING CAM ITSELF IS BUILT INTO THE SOLVER.

have COMPUTING CAMS

The parallax component solver is an example.

Some of the parallax corrections need the value:

$$\frac{1}{\text{Predicted Range}} \times \text{sine of train angle}$$

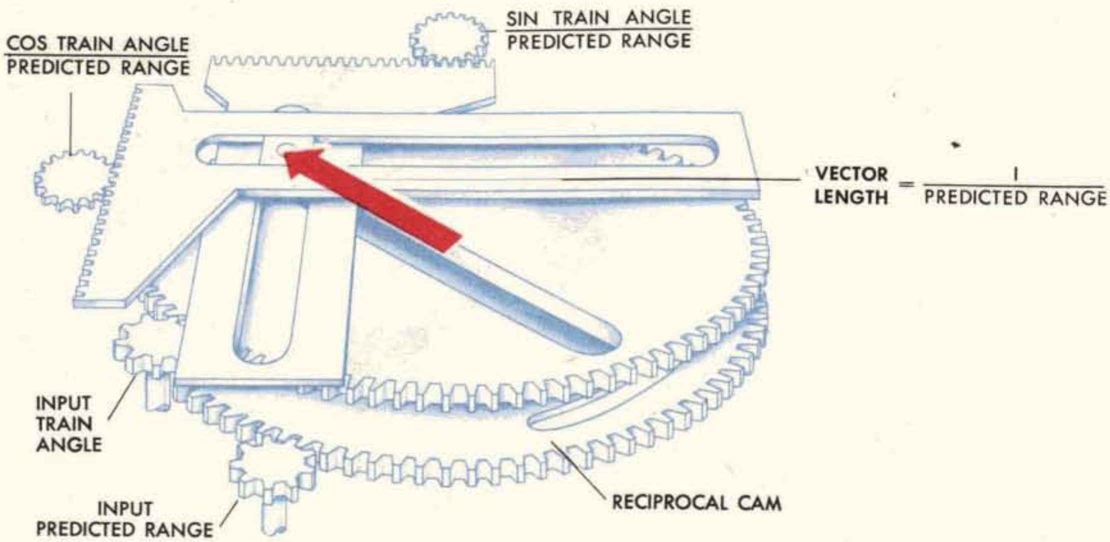
The length of the vector in the parallax solver will be the reciprocal of predicted range.

To compute the reciprocal of predicted range the parallax solver has a reciprocal cam whose input is predicted range.

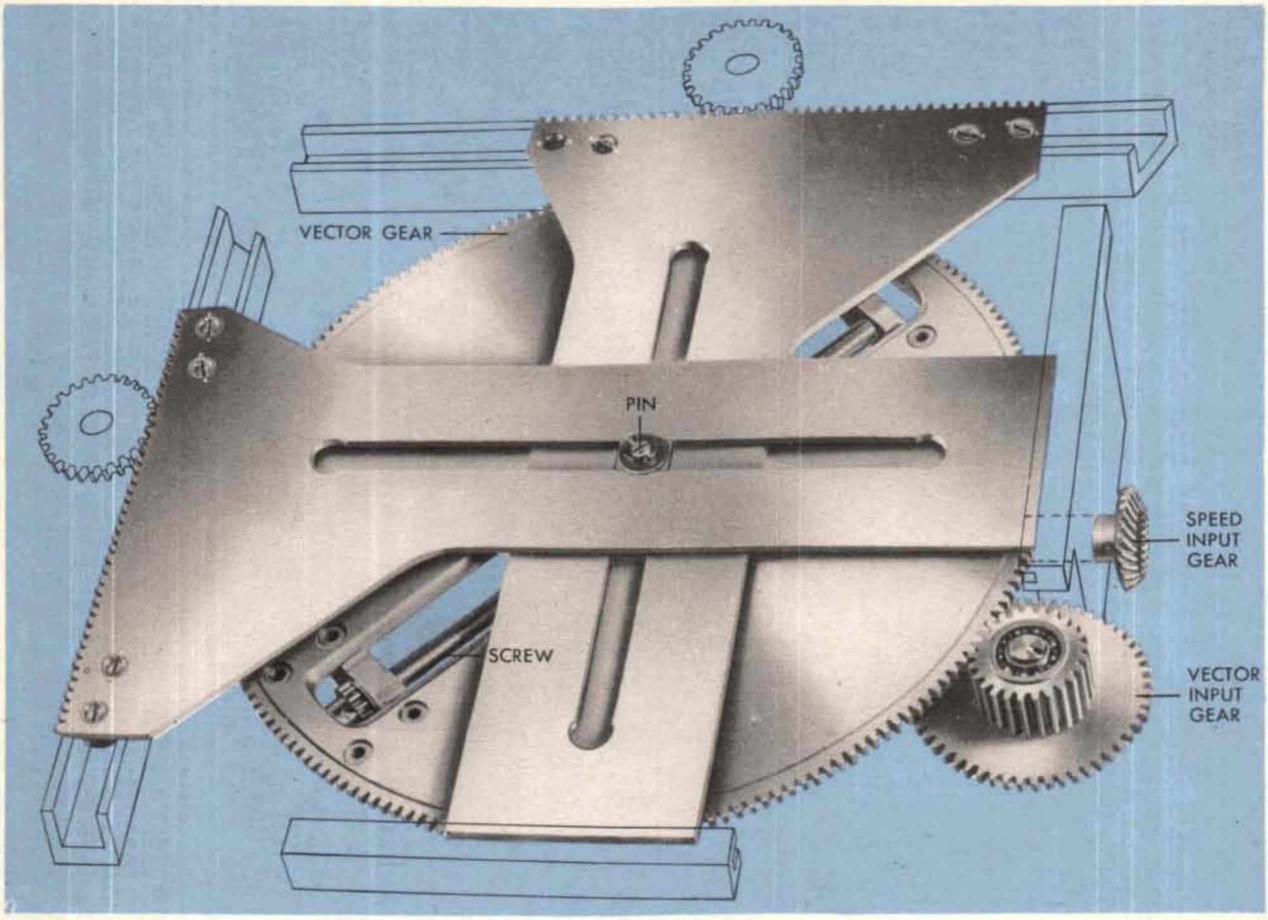
The second input to the solver is train angle (either gun train or director train).

The two outputs will be

$$\frac{\text{Sin train angle}}{\text{Predicted Range}} \quad \text{and} \quad \frac{\text{Cos train angle}}{\text{Predicted Range}}$$



Several kinds of computing cams are used this way in component solvers.

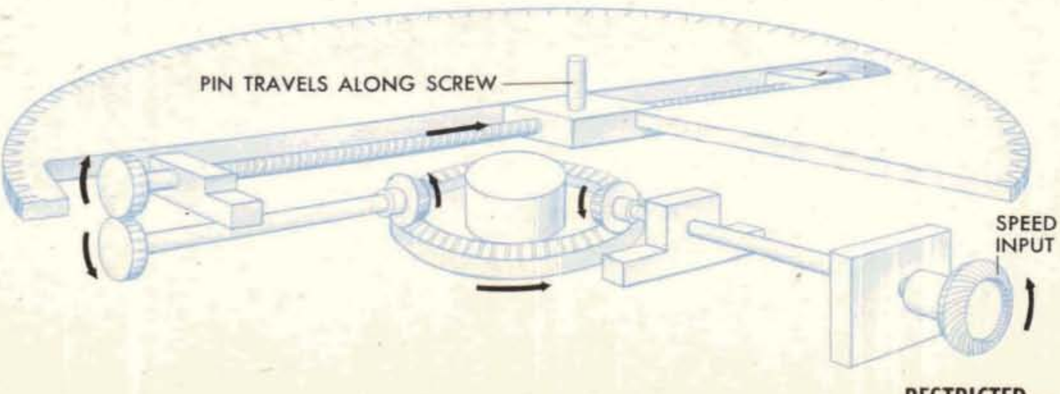


This is a SCREW TYPE component solver

The screw type component solver works very much like the cam type.

It is called the screw type because there is a long screw set in the slot in the vector gear. This screw takes the place of a speed cam—it positions the pin.

The speed input gear drives a line of gearing which turns the long screw. As the screw turns, the pin moves along it, changing the length of the vector.



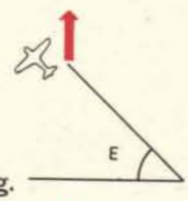
In the cam type component solver the pin can only travel half the width of the cam, i.e., between the center and the circumference.

In the screw type the pin can travel along the screw almost the full width of the vector gear.

The pin can travel along the screw in either of two directions from its center zero position.

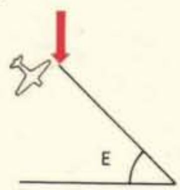
These two directions correspond to positive and negative values.

For any one position of the vector gear the pin can represent vectors in opposite directions. An example is vertical target speed.



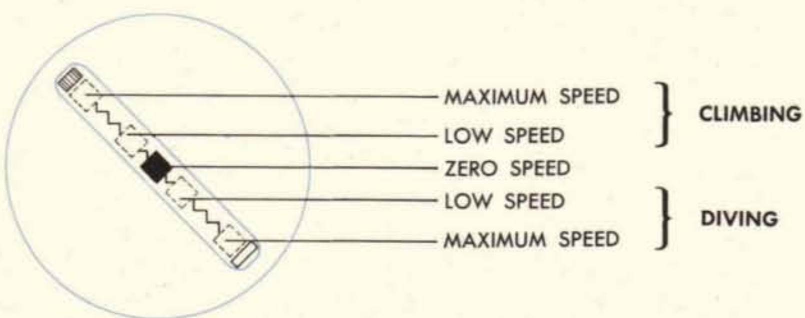
The speed is positive when the target is climbing.

E IS THE SAME IN EACH CASE, BUT THE DIRECTION OF THE VECTOR REVERSES



The speed is negative when the target is diving.

For any angle of the vector slot the pin can show all the speeds from maximum climbing to maximum diving speed:

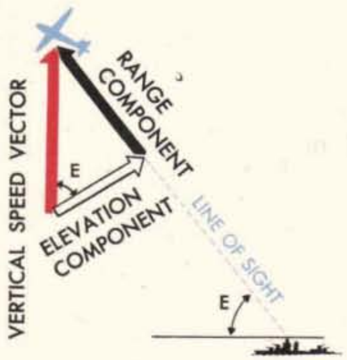


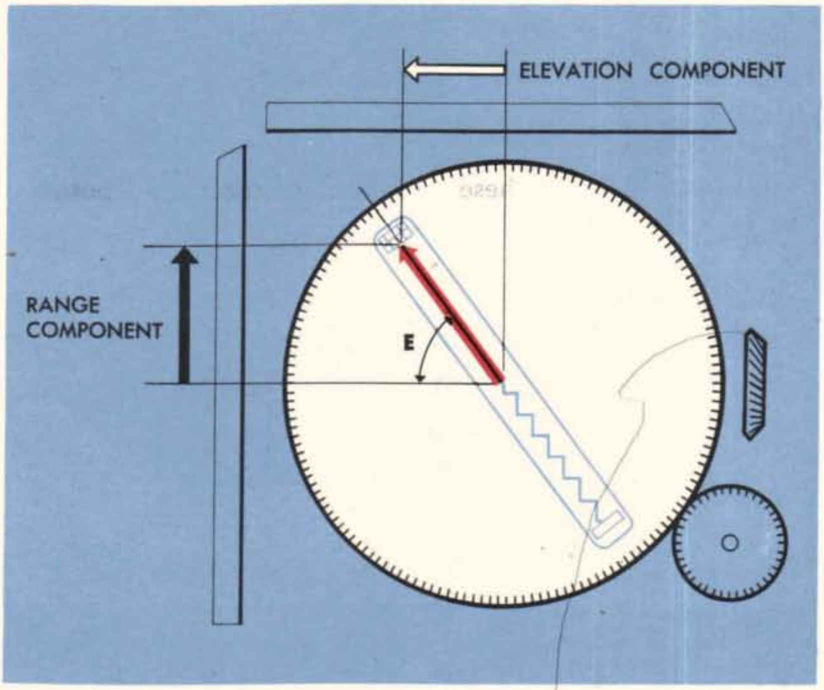
Screw type component solvers

In breaking up the vertical target speed vector, the direction of the slot in the plate must correspond to the angle of elevation, because components are needed:

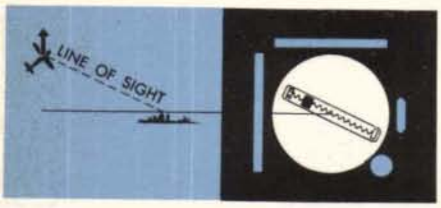
A Along the line of sight for range rate.

B Perpendicular to the line of sight in the vertical plane containing the line of sight, for elevation rate.

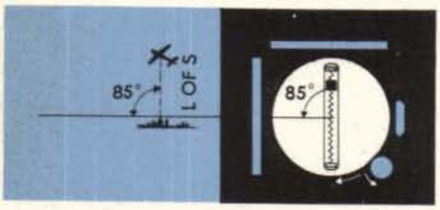




The elevation angle, E, usually varies from a low limit of $-25°$ to a high limit of $+85°$. The vector gear, therefore, need only move between these limits.



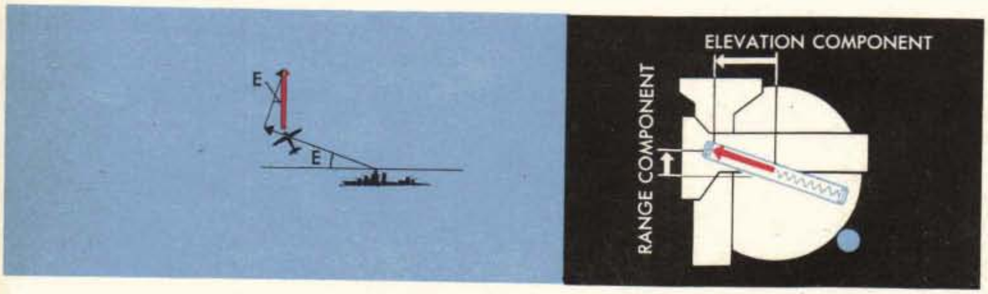
Here the slot is almost horizontal because the target is very near the water.



Here the slot is at $85°$ because the target is almost directly overhead.

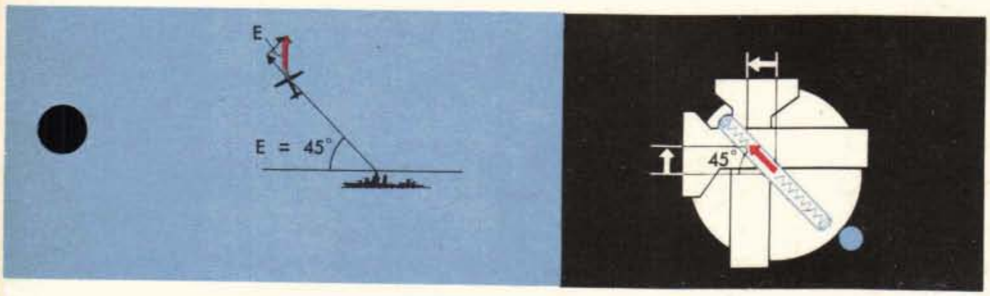
But because the slot goes right across the vector gear, the components can be in either direction, in spite of this limited movement of the vector gear.

Here's how the solver follows the movement of a target . . .



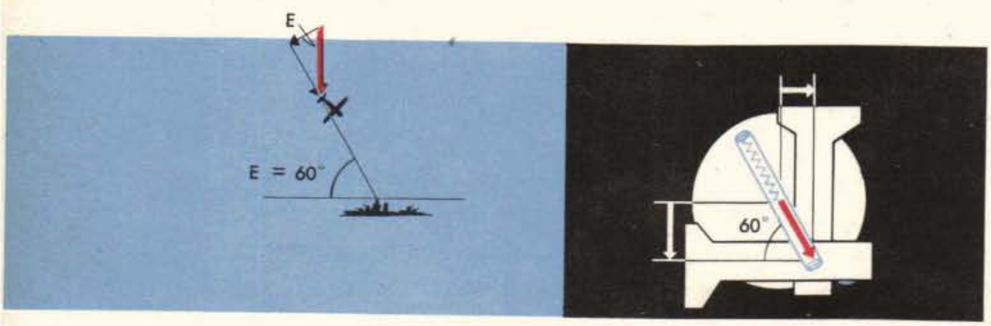
The plane is near the water but rising fast.

The vector is long, with most of the speed in the elevation component.



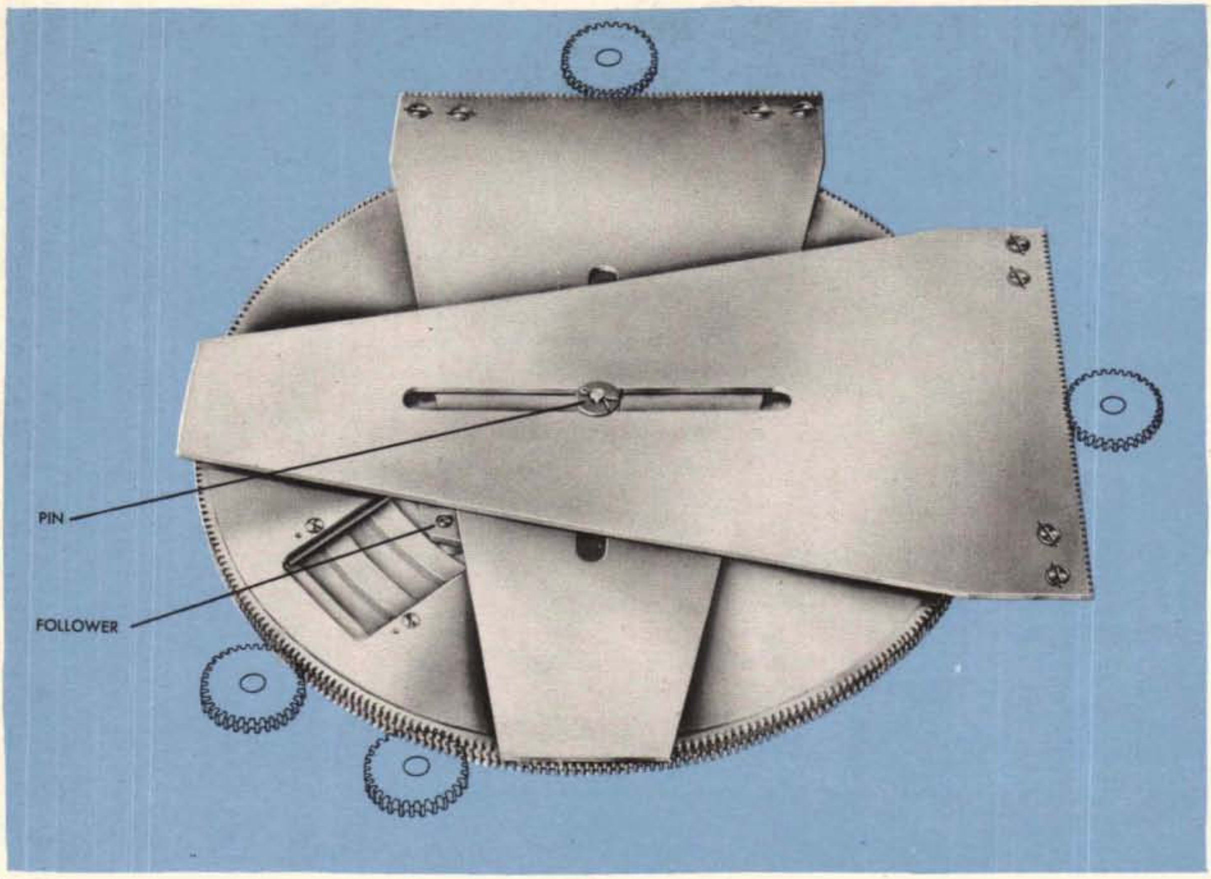
The plane is still climbing. Its elevation now is 45°, the vertical speed is slower and the plane is preparing to go into a dive.

The vector is small and the components are equal.

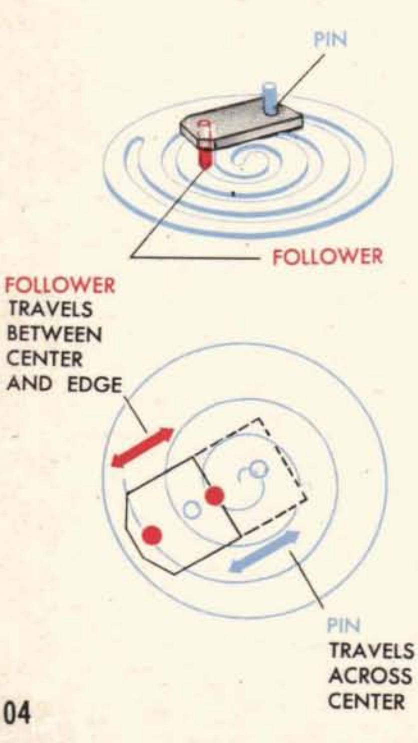


The plane is at 60° elevation, DIVING fast.

THE VECTOR IS IN THE LOWER HALF OF THE PLATE. THE COMPONENTS HAVE REVERSED THEIR DIRECTIONS.



The OFFSET PIN component solver



The offset pin solver is a CAM type designed to give both positive and negative vector lengths for any one position of the vector gear.

In this respect it is like the screw type component solver, but since a cam wears somewhat better than a screw, the offset pin type is often used when the cam input is changing constantly and fast.

The offset pin type has an ordinary constant lead cam.

The cam follower can only move outwards and back from the center to the edge of the cam. In order to use half the motion as positive and half as negative, the pin which moves the racks is offset half this distance from the follower itself.

The follower and the pin are mounted on opposite ends of a steel plate which slides in the vector slot.

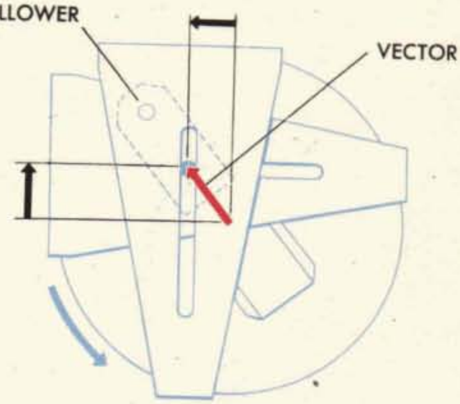
Although the follower only travels from the center to the edge of the cam, the pin travels half this distance EACH SIDE OF THE CENTER.

So for any one position of the vector gear, the outputs on the racks can be positive or negative.

Positive values

When the cam is turned one way the follower moves from zero position towards the edge of the cam. The vector is positive and the racks move in one direction.

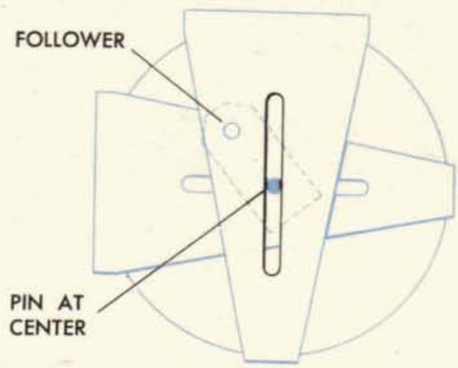
At maximum POSITIVE position, the follower is at the outer end of the cam groove.



Zero position

When the pin is over the center of the solver the racks are at zero. THE FOLLOWER IN THE CAM GROOVE IS ABOUT HALF WAY BETWEEN THE CENTER AND THE EDGE OF THE CAM.

Any one rack is at zero position when its slot is parallel to the slot in the vector gear.

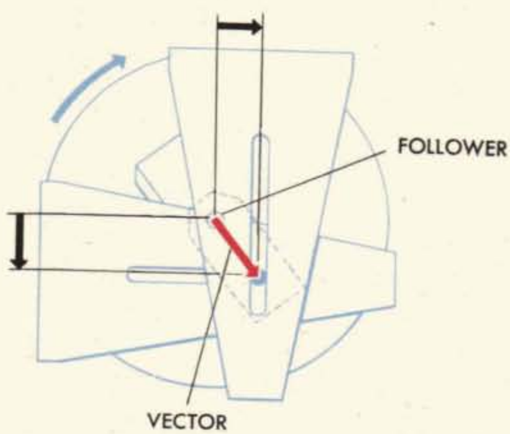


Negative values

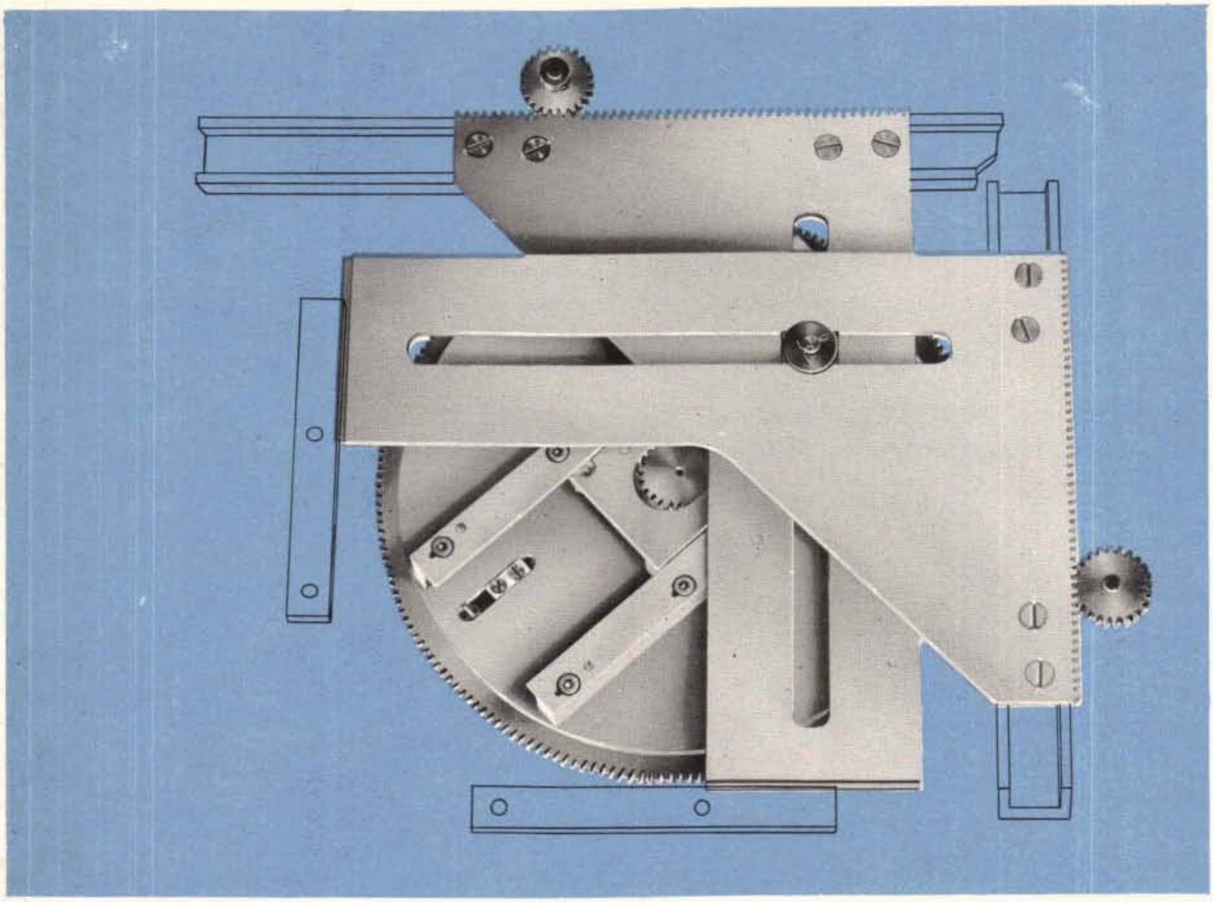
When the cam is turned the other way from zero position, the follower moves toward the center of the cam. The vector is negative and the racks move in the OPPOSITE direction.

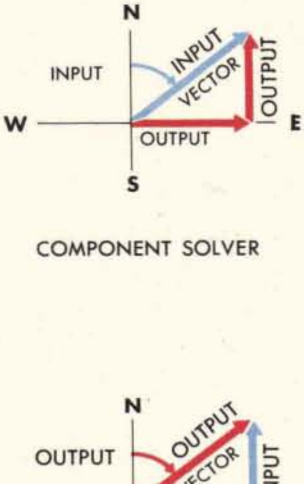
At maximum NEGATIVE position, the follower is at the inner end of the cam groove.

Obviously, either end of the vector slot can be used for positive values—the choice depends on mechanical convenience.



The VECTOR SOLVER





COMPONENT SOLVER

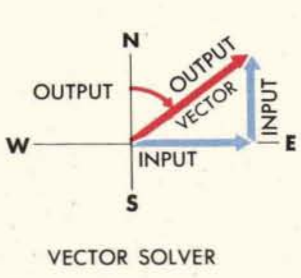
The Vector Solver is like a Component Solver working in reverse.

The Component Solver takes as inputs a speed or distance and an angle and forms a vector. It solves for two components of this vector at right angles to each other.

BUT THE VECTOR SOLVER TAKES AS INPUTS TWO COMPONENTS AT RIGHT ANGLES TO EACH OTHER. WITH THESE COMPONENTS IT FORMS A VECTOR.

The two outputs of the Vector Solver are:

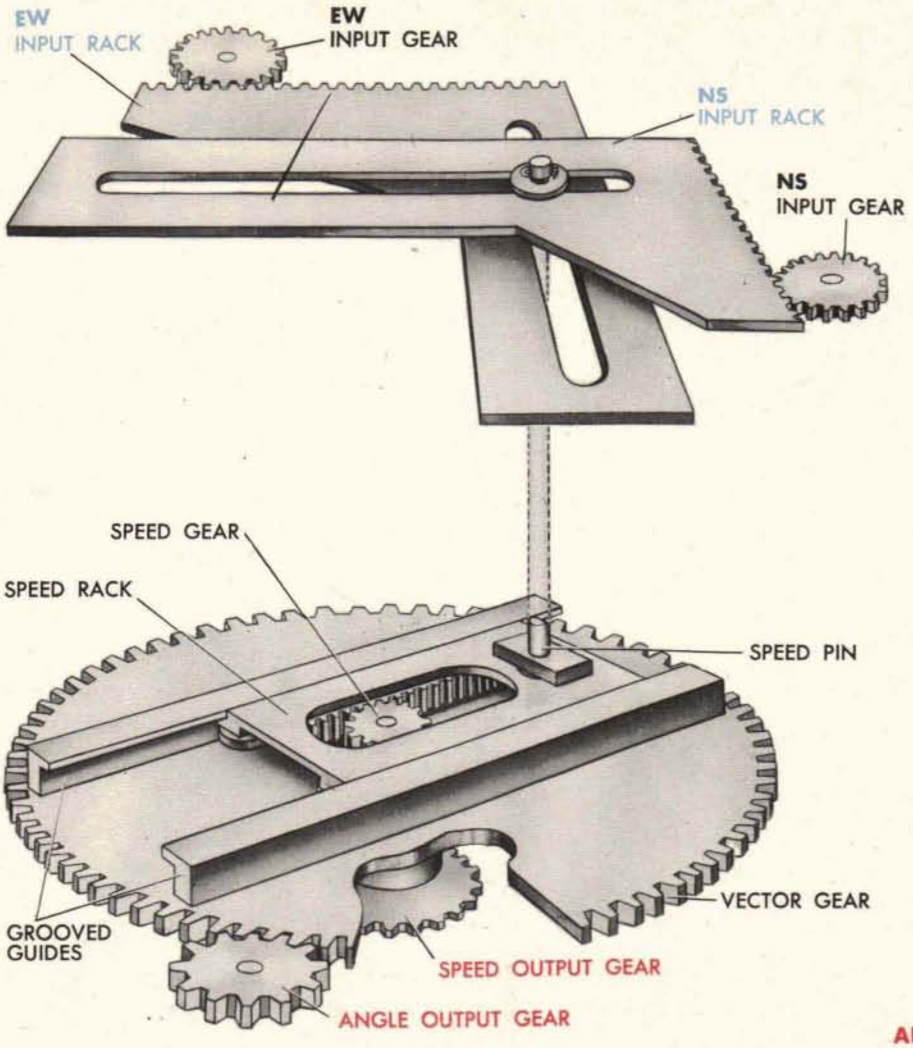
The length of the vector, (usually a speed)
The direction of the vector, (always an angle)

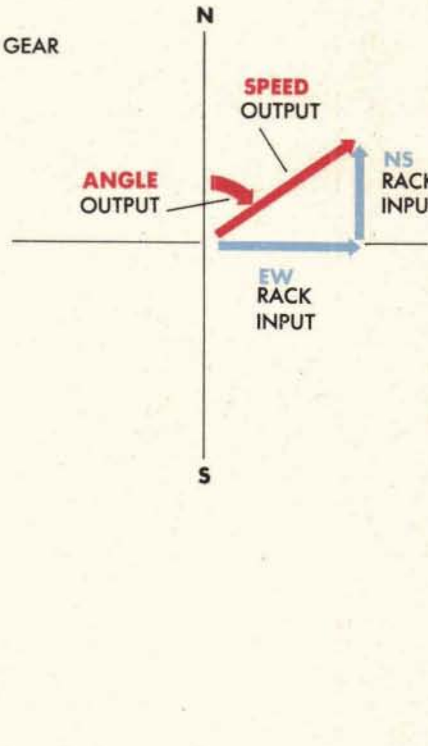


VECTOR SOLVER

Usually an *approximate* vector is first set into the Vector Solver by positioning the speed pin and the vector gear. When this is done all the vector solver parts move as in a Component Solver.

The *approximate* vector is then corrected by the movement of the two input racks. The input racks push the speed pin and rotate the vector gear to new positions to form a new vector of correct length and direction.





How the INPUT RACKS set up a VECTOR

A speed pin comes up through the slots in these two racks so that the position of the pin changes with every input movement of either or both racks.

The other end of the speed pin is anchored to a speed rack.

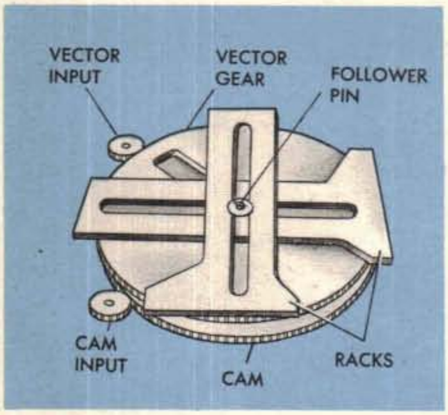
The speed RACK slides between the two grooved guides fastened to the vector gear, whenever the speed PIN moves across the vector gear.

The speed gear at the center of the vector gear meshes with the speed rack. Movement of the speed rack along its guides rotates the speed gear.

The speed gear turns an output gear below the vector plate.

Movement of the input racks and the speed pin also causes the VECTOR GEAR to TURN.

The vector gear turns the angle output gear.



Setting a CAM TYPE COMPONENT SOLVER

Here are the parts of a Cam Type Component Solver to be set

1. The vector gear
2. The cam

and the parts of the solver which aid in setting

1. The follower pin
2. The racks

The *inputs* go to the vector gear and the cam, which together position the pin. The pin, in turn, positions the racks.

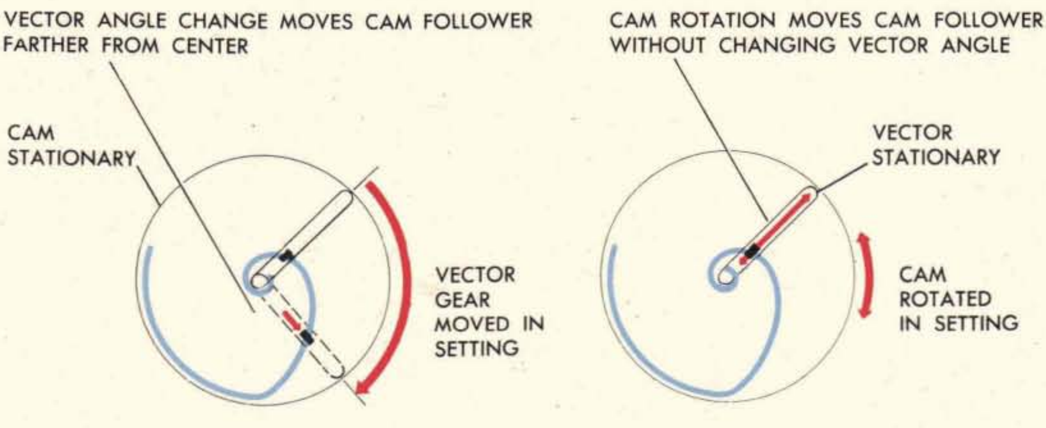
The *outputs* come off the racks.

CAUTION

ALWAYS TURN THE CAM OR VECTOR GEAR SLOWLY AND CAREFULLY WHEN SETTING.

Spinning the vector gear or cam before setting is completed will drive the cam follower against the end of the cam groove and damage the cam follower pin.

ALWAYS MAKE THE VECTOR GEAR SETTING FIRST.



THE VECTOR GEAR SETTING CHANGES THE CAM SETTING WHEN THE CAM IS STATIONARY

THE CAM SETTING DOES NOT CHANGE THE VECTOR GEAR SETTING

The vector gear

ROUGH SETTING

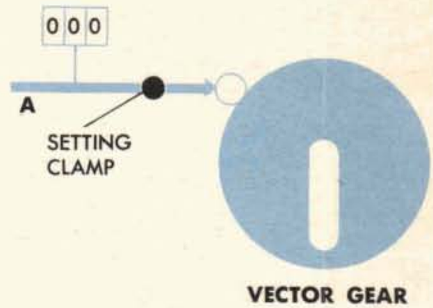
The *vector gear* is positioned by input shaft A, which also positions the counter.

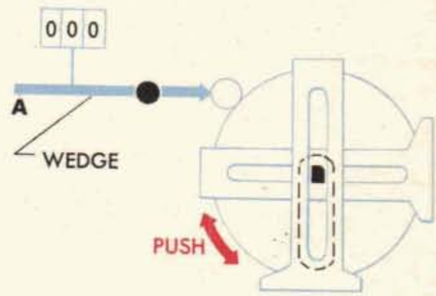
The purpose of setting the vector gear to the counter is to join them so that the position of the slot will be exactly the position indicated on the counter.

1. Turn input A until the counter reads zero. Wedge the input.
2. Push the vector gear until the vector slot points in the right direction for the zero setting. The vector slot should be parallel to one output rack.

   NOTE: A computer's setting notes give the readings and the vector gear directions for its component solvers.
3. Slip-tighten the setting clamp.
4. Remove the wedge.

The fine setting of the vector gear will be made later.





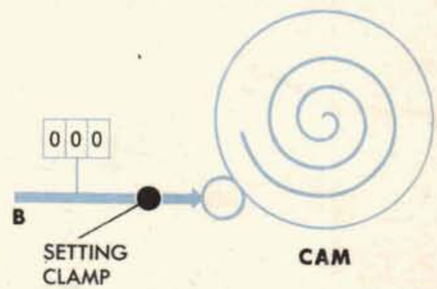
The cam

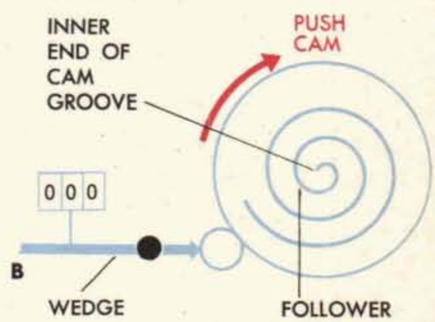
ROUGH SETTING

The *cam* is positioned by input shaft B which also positions the counter. In setting, the purpose is to join the cam and the counter through the setting clamp so that the position of the cam is exactly indicated by the counter.

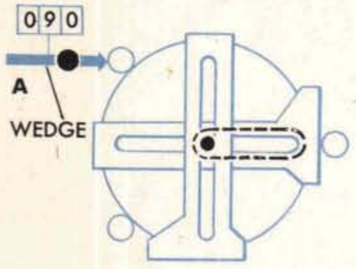
1. Turn cam input B until the counter reads zero. Wedge the input.
2. Push the cam until the follower goes to the inner end of the cam groove; then back it off a little so that the follower will not hit the end of the groove.
3. Slip-tighten the setting clamp.
4. Remove wedge.

The fine setting of the cam will be completed later.



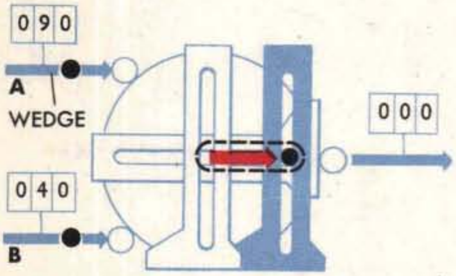


To refine the setting of the vector gear



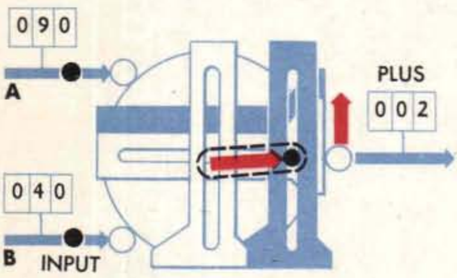
SLOTS PARALLEL

1 Turn the vector gear until its slot is parallel with the slot in one of the output racks. Wedge the input.

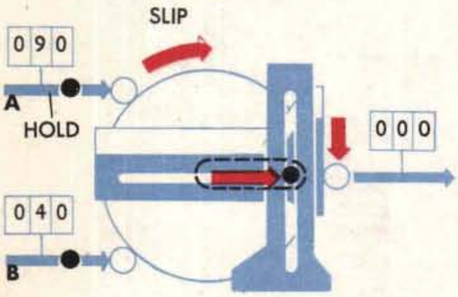


2 Starting with the pin at the center of the cam, turn the cam to bring the pin to the outer radius of the cam. As the pin moves, observe any motion of the output rack with the counter indicator on it.

3 Here there is *no* motion.... The vector gear is set correctly because the slots are exactly parallel and the pin can travel along the slots without moving the output rack.



4 Here the vector gear setting is incorrect. The vector gear slot is not parallel to the slot in one of the output racks, and as the pin travels along the slots the output rack moves. The distance the counter indicator moves represents the amount of error in the setting.



5 To correct this error: With the input still wedged, slip the vector gear until the output rack with the counter indicator on it returns to its original position.

The movement of the output rack is always proportional to the distance the pin moves from the center.

Always correct with the pin at the outer radius because this position will give the maximum movement of the output rack which has the counter indicator on it.

6 Repeat steps 2 and 5 until there is a minimum motion on the counter indicator.

7 Tighten the setting clamp.

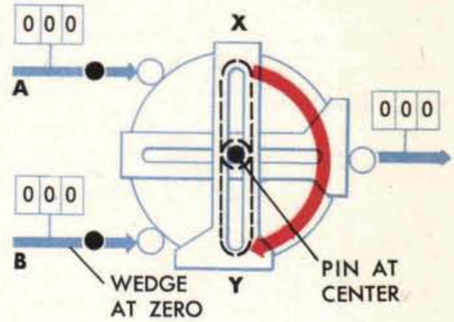
8 Remove wedge from input shaft.

To make the **fine** setting of the cam

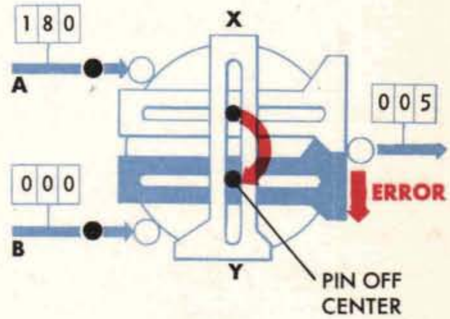
1 Turn cam input *B* until the counter reads zero. Wedge the input.

2 Starting with the vector slot in position *X* turn it to position *Y*. As the vector gear moves, observe any motion of the output rack with the counter indicator on it.

3 Here there is *no* motion ... The cam is set correctly because the pin is right over the center and the vector gear slot can turn around without moving the output rack.

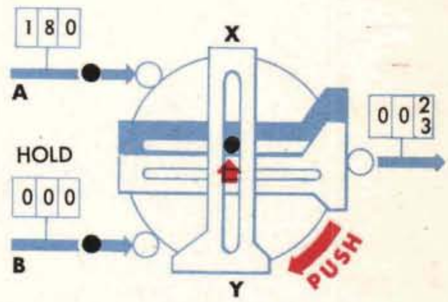


4 Here the cam setting is incorrect. The pin is a little way from the center, so when the slot is turned around, the pin is moved and the pin, in turn, moves the output rack with the counter indicator on it.



5 To correct the setting, slip the cam in the direction which returns the output rack halfway to its original position.

Always correct with vector slot at *X* or *Y* because these positions give the maximum movement on the output rack.

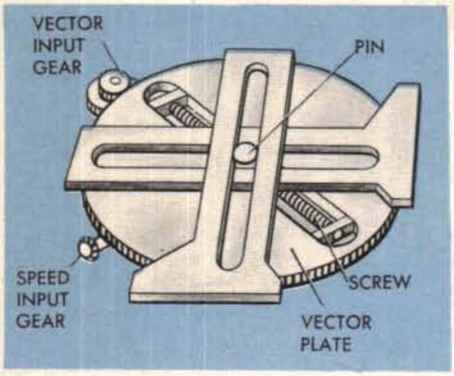


6 Repeat steps 2 and 5 until there is minimum movement of the output rack with the counter indicator on it.

7 Tighten the setting clamp.

8 Remove wedge.

Setting a SCREW TYPE

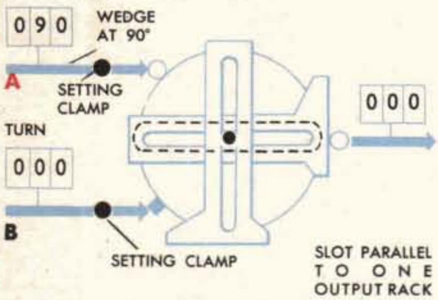


The screw type component solver is very similar to the cam type. The only difference is that the pin travels along a *screw* instead of *in a cam groove.*

In the screw type component solver the vector slot extends across almost the whole gear. So the pin can travel either side of the center and it can move the whole length of the vector gear slot for any given vector setting.

CAUTION: Set the vector gear first.

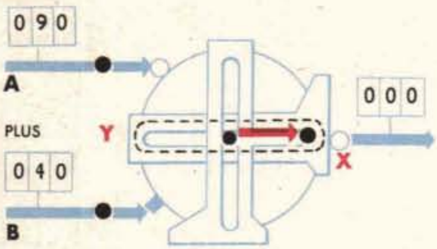
To set the vector gear



1 Turn input shaft *A* until the counter reads ninety degrees. Wedge this input.

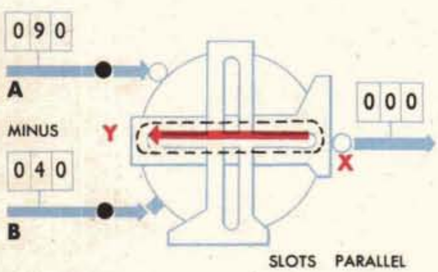
2 Push the vector gear until the slot points in the right direction for the ninety degree setting. In this example the vector gear slot is parallel to the slot on the output rack with the indicator counter.

NOTE: A Computer's setting notes give the readings and the vector gear directions for its component solvers.



3 Slip-tighten the setting clamp.

4 Turn input shaft *B* to move the pin from the *center* to the *X* end of the screw.

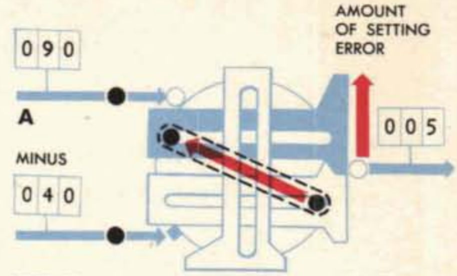


5 Now run the screw from *X* to *Y*. Observe the motion of the output rack indicator counter.

6 Here there is *no* rack motion . . . the vector gear is set correctly . . . the two slots are parallel.

COMPONENT SOLVER

7 Here the vector gear setting is incorrect. The two slots are not parallel, so the motion of the pin causes the output rack to move. The distance the counter indicator moves represents the amount of error in setting.

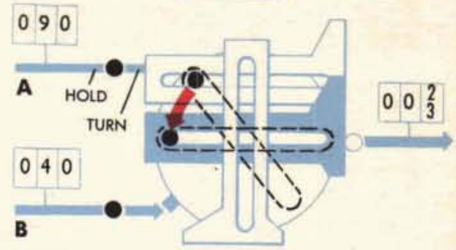


8 To correct this error, slip the vector gear until the output rack with the counter indicator returns to a position half way back to its original position.

9 Repeat 5 and 8 until there is minimum motion of the indicator.

10 Tighten the setting clamp.

11 Remove wedge.

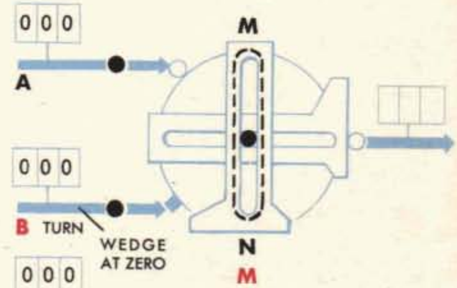


To set the screw

1 Turn input shaft *B* until the counter reads zero. Wedge the input.

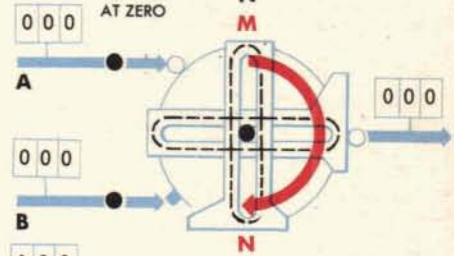
2 Turn the screw until the pin is at the center of travel. This is the approximate zero position of the pin.

3 Slip-tighten the setting clamp.

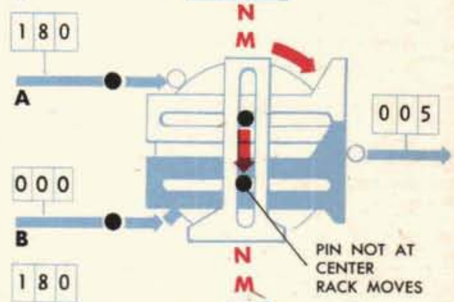


4 Using input shaft *A*, turn the vector gear so that its slot moves from *M* to *N*. Observe the motion of the output rack with the counter indicator on it.

5 Here there is *no* motion . . . the screw is set correctly. The pin is at the center and the vector gear slot can turn around it without moving the output.

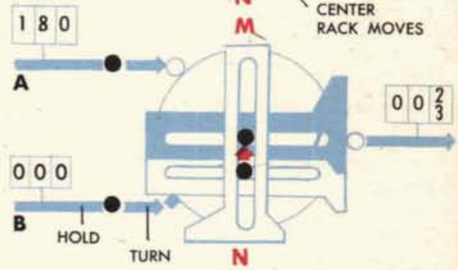


6 Here the screw setting is incorrect. The counter indicator shows the distance the rack moved. This distance represents the amount of error in setting.



7 To correct the error, slip the input B to the screw until the pin moves enough to bring the output rack with the counter indicator half way back to its original position.

Always correct with the vector slot at *M* or *N* because this position gives the maximum movement on the indicator.

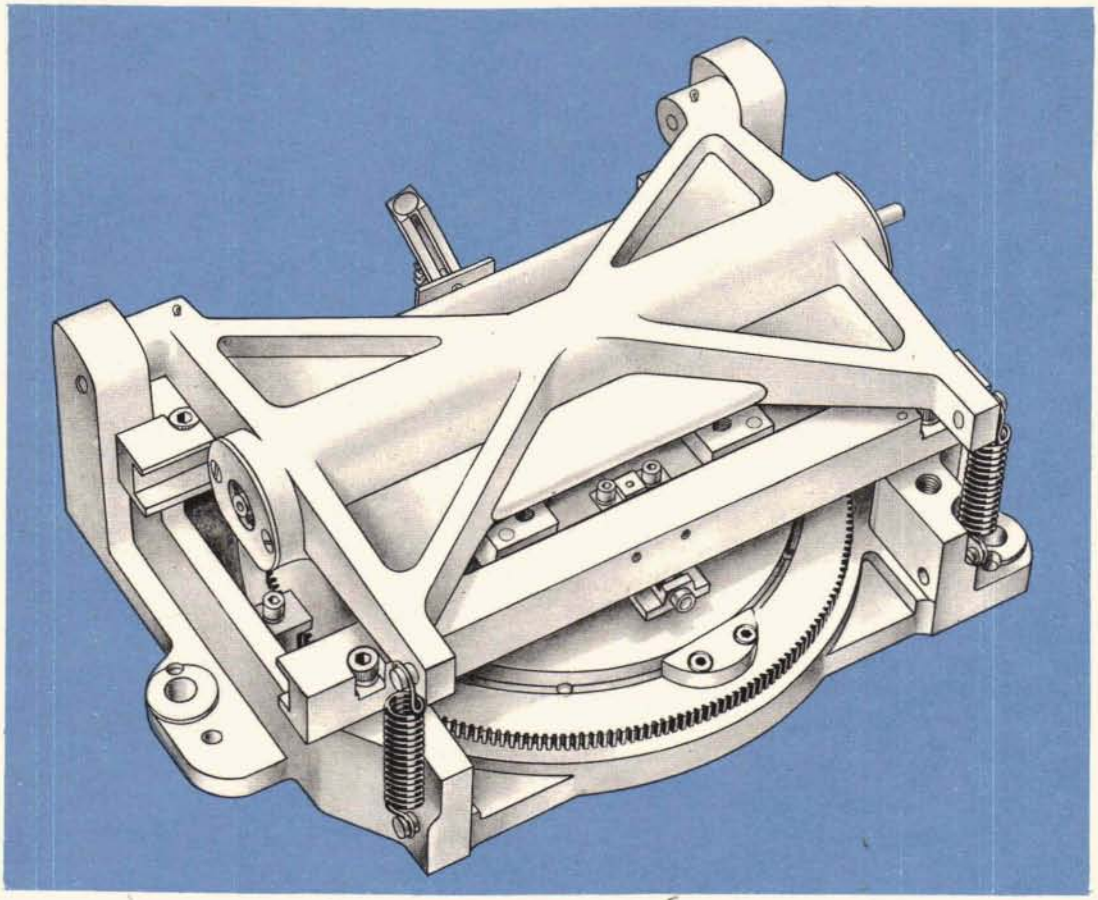


8 Repeat 4 and 7 until there is minimum motion of that indicator.

9 Tighten the setting clamp.

10 Remove wedge.

DISK TYPE INTEGRATORS

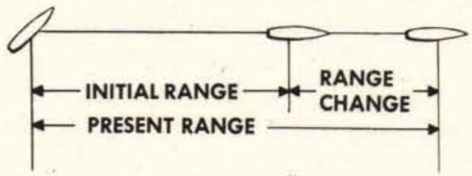


Disk integrators can do a variety of jobs, some of them quite complicated. One of their simplest uses is "keeping the range." By seeing how the integrator does this simple job, it is possible to get a pretty good idea of how it works.

It must be remembered though, that while a description of an integrator keeping the range is a good introduction, it is not the whole story of what integrators can do.

The integrator acts like a variable gear ratio

A Rangekeeper or computer keeps the range by computing the *changes of range* as they occur, and adding them to the initial observed range.

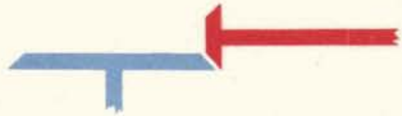


Change of range for a constant range rate is computed by multiplying the *Rate* at which range is changing by *Time*.

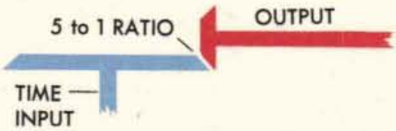
Range rate $\times$ time $=$ change of range during that time.

5 yds. per sec. $\times$ 1 sec. $=$ 5 yds. change of range in one second.

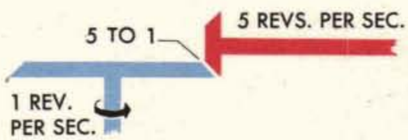
5 yds. per sec. $\times$ 60 sec. $=$ 300 yds. change of range in one minute.



This multiplication could be done by a gear ratio. The larger gear could represent *time*. Let the ratio be 5 to 1.



If the time gear is turned once per second the output gear will turn 5 revolutions per second. Let each revolution of the output shaft represent one yard and the simple change of range problem above is solved:

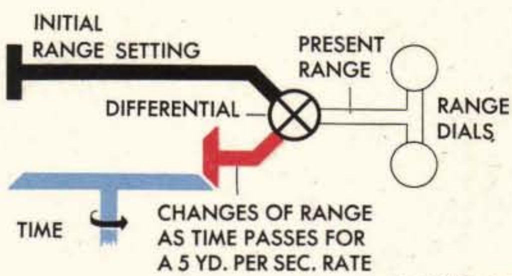


The large gear represents *time*

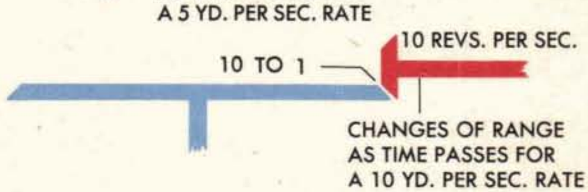
The ratio represents *range rate*

The output represents *change of range*

Connect the output shaft to a range dial by reduction gearing, and the moving range dial will indicate the range at any instant AS LONG AS THE RANGE RATE STAYS AT 5 yds. per sec.



Suppose the range rate changes to 10 yds. per sec. The time input gear must continue to turn at the same speed, because it represents time. So another set of gears would be needed with a ratio of 10 to 1.



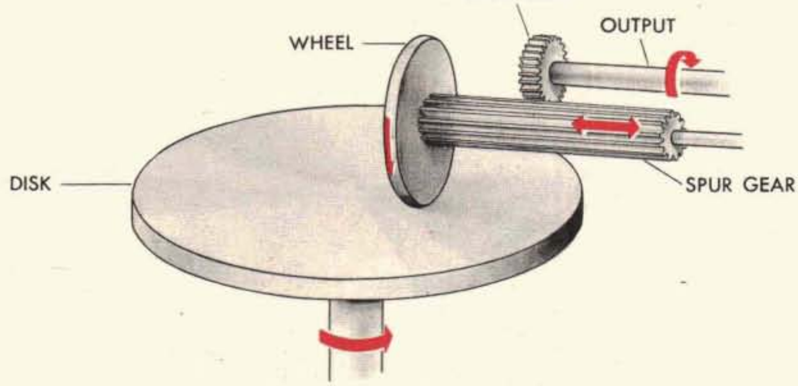
EVERY DIFFERENT RANGE RATE REQUIRES A DIFFERENT GEAR RATIO TO COMPUTE RANGE CHANGE. The problem then is to set up a

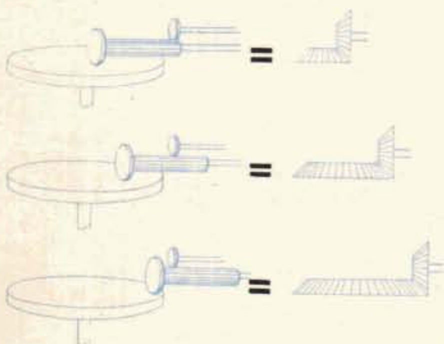
VARIABLE GEAR RATIO

The disk integrator is one answer to this problem.

TWO TYPES OF
The WHEEL type

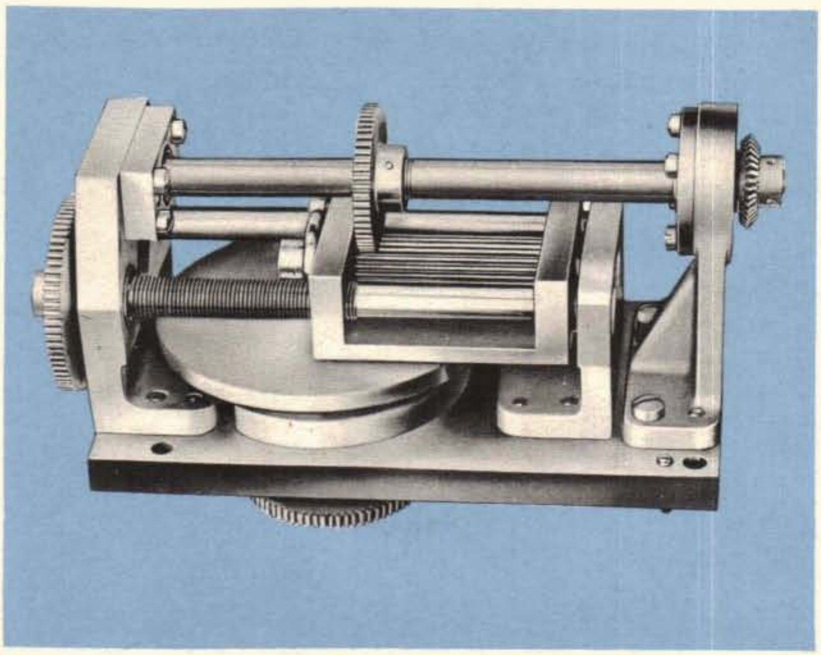
Here is one way to construct a variable gear ratio.





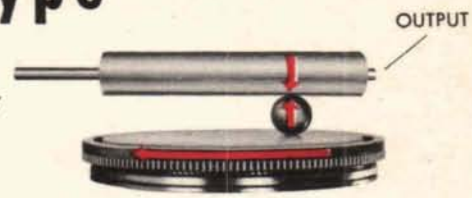
The disk takes the place of the large time input bevel gear. The wheel replaces the small output bevel. The wheel can be positioned at different distances from the center of the plate to get different output ratios.

One of the integrators in actual use is constructed this way.



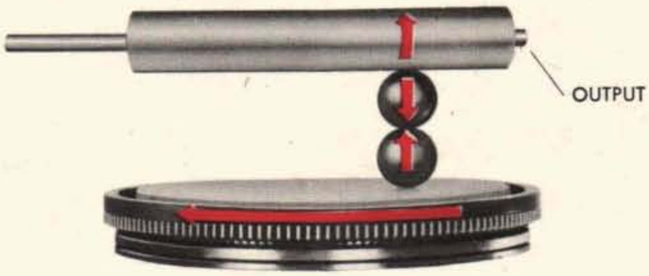
INTEGRATORS

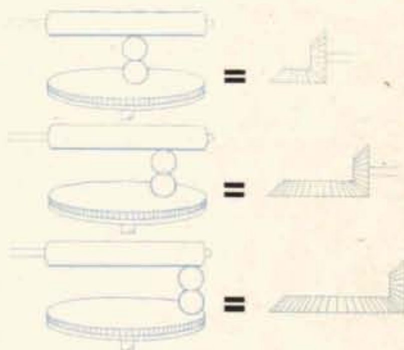
The BALL and ROLLER type



A ball and roller may be used instead of the wheel and spur gears.

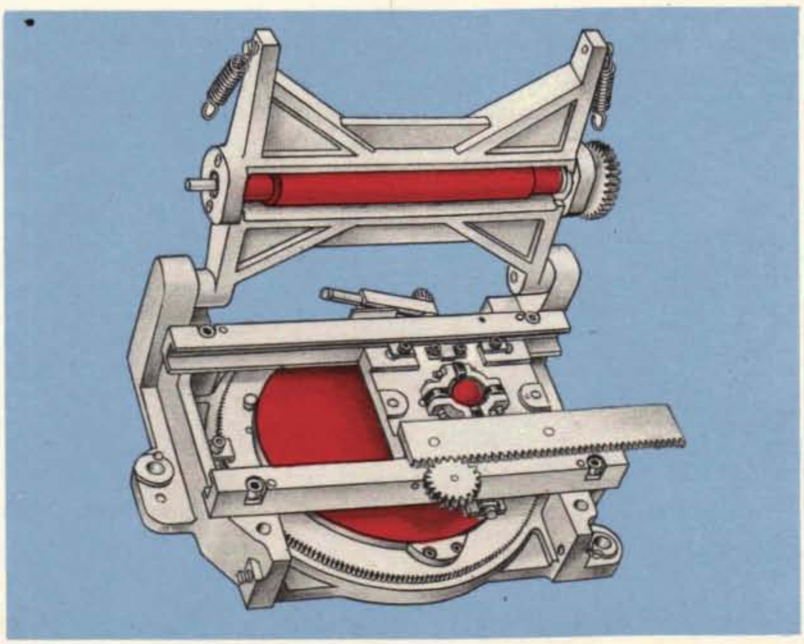
If two balls are used they will move across the face of the disk more easily than one.



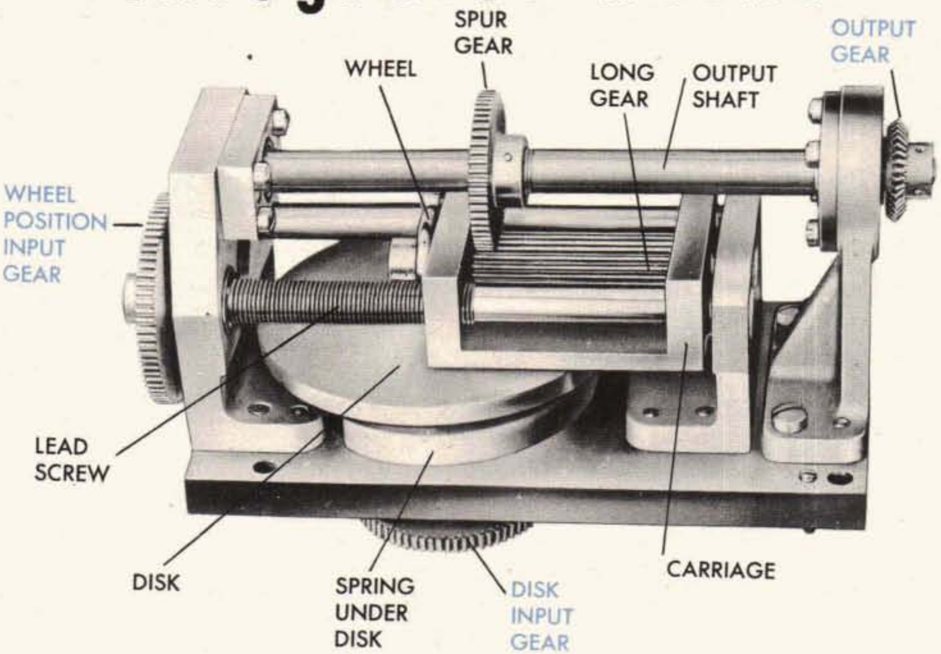


In this case the two balls take the place of the small bevel.

This is the ball and roller type opened up for a look inside.



How the wheel type integrator works



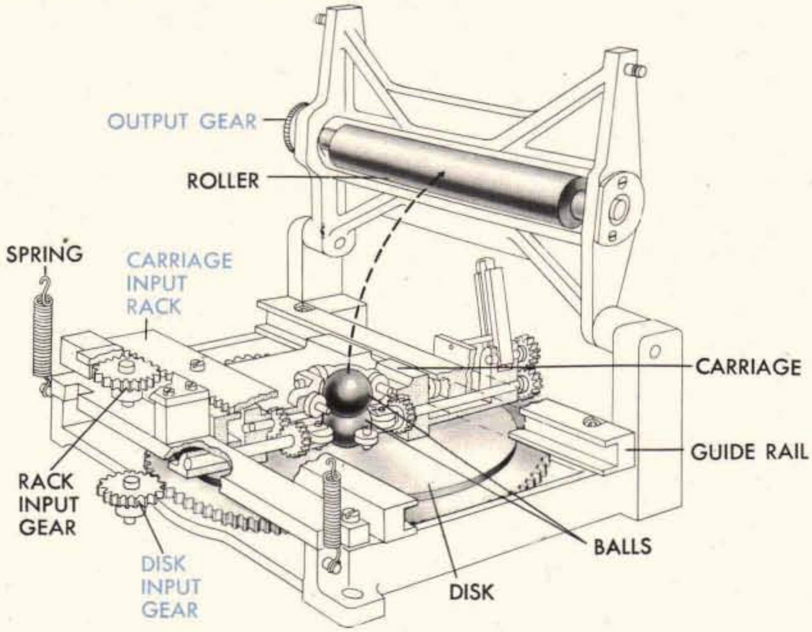
The disk is turned by a gear.

The wheel is positioned by a lead screw. In the unit shown above the wheel will move only half the width of the disk.

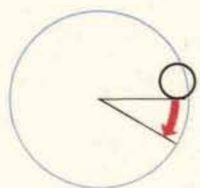
The output is transmitted to a shaft by a spur gear which stays in mesh with the long gear as it moves back and forth with the carriage.

The disk and wheel must be held together tightly to prevent the wheel from slipping. The necessary pressure comes from a spring under the disk.

How the ball and roller type integrator works



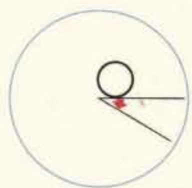
In the ball and roller type, the disk is mounted on a gear and is turned directly by an input gear in mesh with it. In this integrator the disk is 5″ across.



The two steel balls, one on top of the other, are held in position by a carriage which runs along a pair of guide rails across the face of the disk.

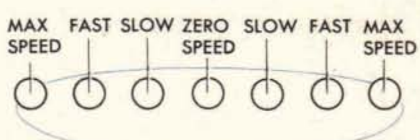
The balls turn the roller, which has an output gear at one end.

The balls can be positioned by the carriage anywhere along a straight line from one edge of the disk across the center to the other edge.



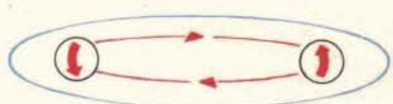
The circumference of the circle passing under the balls is greater when the balls are near the edge of the disk than when they are near the center.

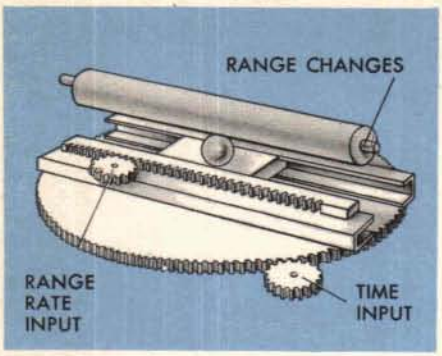
So the balls rotate fastest when they are at the edge of the disk, slower towards the center.



On one side of the center the balls turn in one direction, on the other side of the center in the opposite direction.

The pressure needed to hold the balls against one another, and against the disk and roller comes from two springs. Each of them exerts about a nine pound pull.





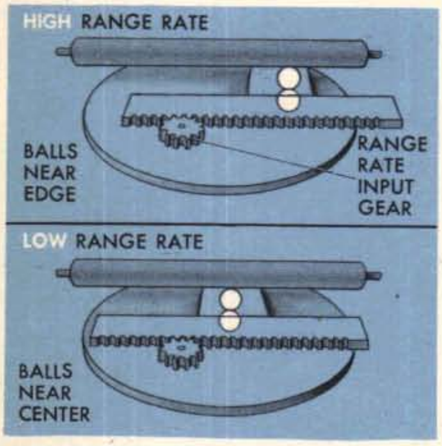
NOTE:
It is assumed in this description that the speed of rotation of the bottom ball is determined only by its distance from the center of the disk. Actually its speed of rotation is affected also by two tiltable rollers. See pages 128-129.

How an INTEGRATOR

Time Input

When the target is picked up, the Initial Range is set into the range dial. At that moment, the Time Motor is turned on, setting the disk in motion. The rotating disk, then, can be compared to a clock which is constantly ticking away the passage of time from the instant the target is first sighted up to each new range reading.

In the range problem the disk always rotates in the same direction at a constant speed. This is a mechanical way of saying that TIME, which the disk represents, always goes by and never backs up.



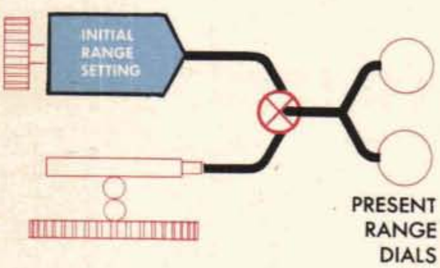
Range rate input

Range rate is fed from component solvers into the carriage input gear, which positions the carriage and the balls according to this rate.

If the range rate is fast, the carriage will locate the balls away from the center near one edge of the disk.

If the rate is slow, it will locate them near the center of the disk.

The speed of the balls depends on their distance from the center of the plate SO THE SPEED OF THE BALLS IS ALWAYS PROPORTIONAL TO THE RANGE RATE.



Output

The output roller is constantly being turned by the balls. Sometimes it turns rapidly, sometimes slowly, according to the rate input.

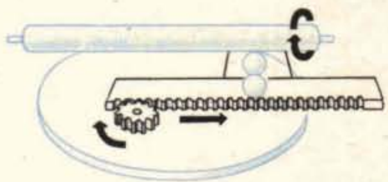
THE POSITION OF THE ROLLER AT ANY MOMENT, THAT IS, THE NUMBER OF REVOLUTIONS IT HAS MADE FROM ITS INITIAL POSITION, TELLS THE ACTUAL CHANGE IN RANGE DURING THE TIME THE DISK HAS BEEN TURNING.

The output roller is geared to the range dial through a differential, so that this change in range is constantly being added to the initial setting to give present range at any moment.

keeps the range

Plus and minus RANGE RATES

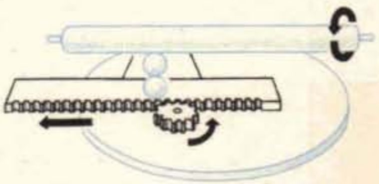
When Range is increasing, changes of Range are being ADDED to Initial Range. The Range rate is PLUS.



When Range is decreasing, changes of Range are being SUBTRACTED from Initial Range. The Range Rate is MINUS.

A PLUS range rate will turn the rate input gear in one direction positioning the carriage toward one side of the disk.

The balls and roller turn in the direction to ADD range changes.



The MINUS range rate will turn the rate input in the opposite direction, moving the carriage toward the opposite side of the disk. The balls and roller will *reverse* and start subtracting range changes.

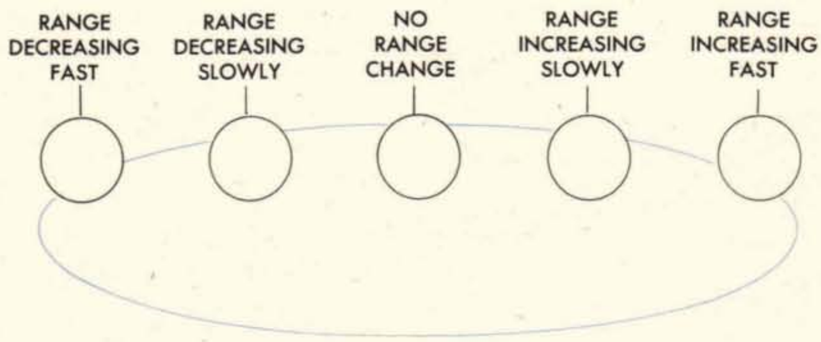
Always remember this:

The DISTANCE of the balls from the center depends on the value of the range rate.

The balls are on one side of the center or the other, depending on whether the range rate is PLUS or MINUS.

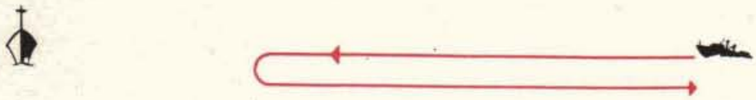
The rate will be PLUS if range is INCREASING.

The rate will be MINUS if range is DECREASING.

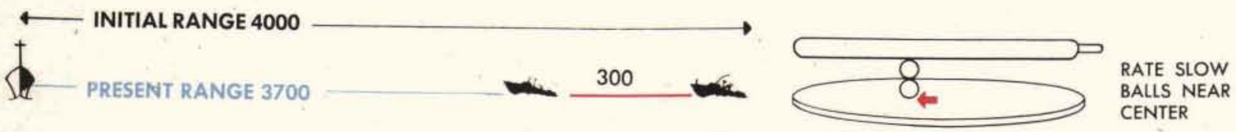


A simple RANGE PROBLEM

Suppose that a torpedo boat attacks own ship, increasing its speed as it comes closer. To simplify the problem the speed of the torpedo boat is assumed to change instantly and remain at the new speed until changed again. Own ship does not move.



Torpedo boat picked up at 4000 yards range. Speed 300 yds. per min. It proceeds at this speed for one minute.

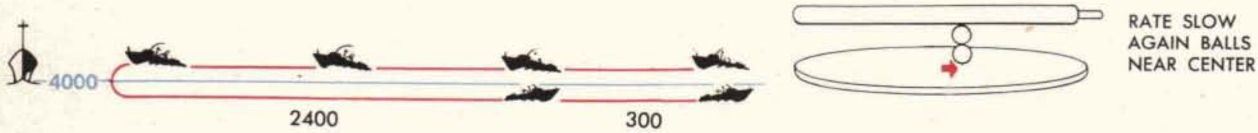


Then its speed increases to 600 yds. per min., and it runs at this speed for two minutes, covering 1200 yards.

Then the speed increases to 1200 yds. per min., and it runs at this speed for one minute.

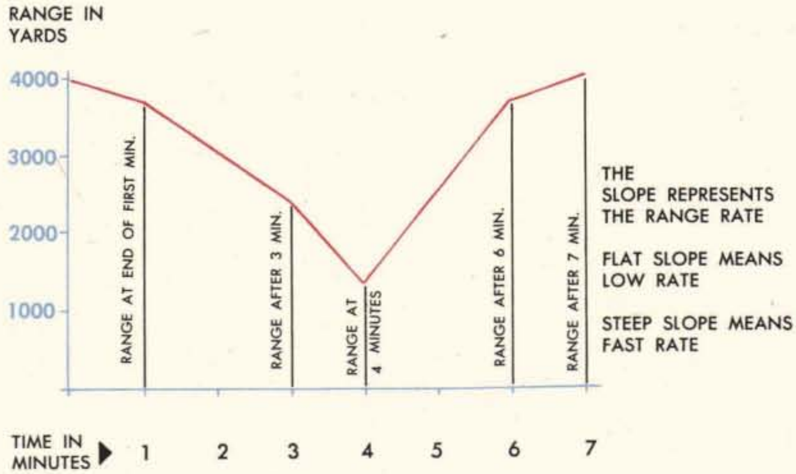
Then the boat releases the torpedoes and reverses its course. It travels for two minutes at 1200 yds. per min.

The speed is then reduced to 300 yds. per min., and after one minute the torpedo boat is back at its starting range.



This problem can be summarized in a chart:

300 yds./min. × 1 min. — 300 yds. range change (less)
600 yds./min. × 2 min. — 1200 yds. range change (less)
1200 yds./min. × 1 min. — 1200 yds. range change (less)
1200 yds./min. × 2 min. — 2400 yds. range change (more)
300 yds./min. × 1 min. — 300 yds. range change (more)



Of course no ship behaves so simply. The speed of a ship does not increase in jumps, it increases gradually. But the position of the balls, which represents range rate, can also be changed gradually, while the time disk is running.

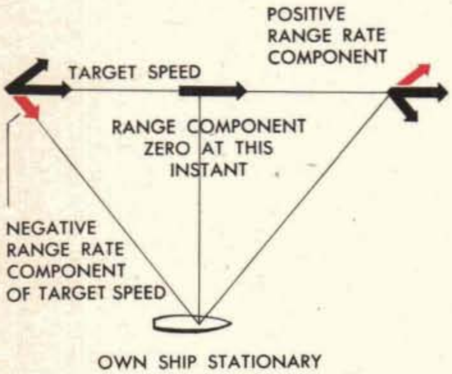
The balls do not wait until they have reached a fixed position before they start registering changes of range for the new rate.

AS THE BALLS MOVE THEY WILL CONTINUOUSLY CHANGE IN SPEED OF ROTATION IN DIRECT PROPORTION TO THEIR CHANGING DISTANCE FROM THE CENTER OF THE DISK.

In this way the integrator keeps on multiplying continuously as the balls move. It can multiply a continuously changing rate by time, and the roller will accurately accumulate the resulting changes of range.

A charted line showing present range during any actual torpedo boat attack would be straight when speed was constant and *curved* during changes of speed.

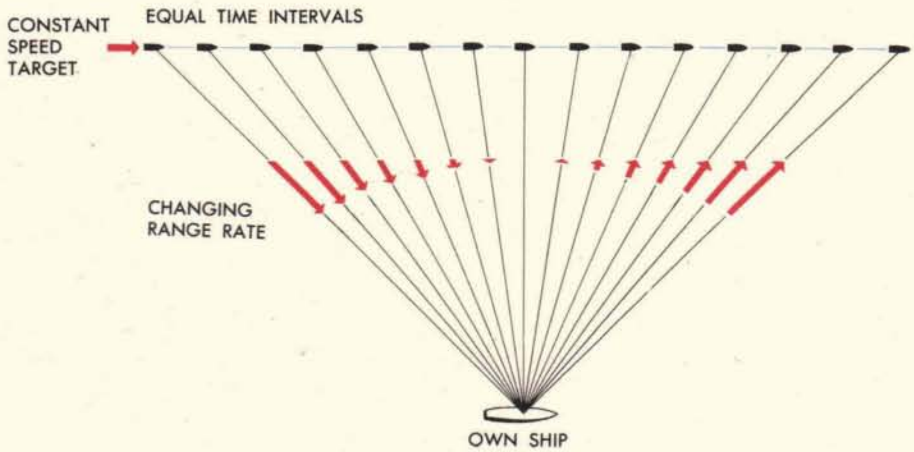
A range rate that continually

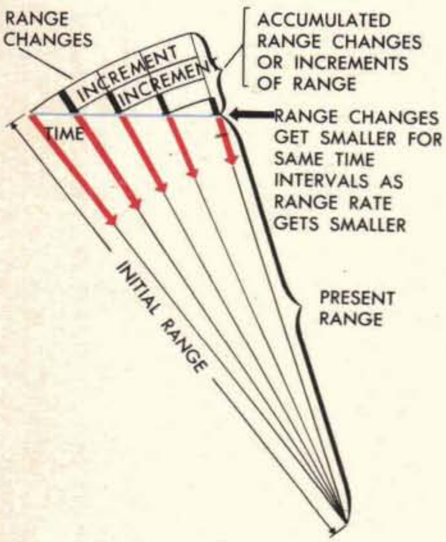


No matter how often or how gradually the range rate changes, an integrator can keep track of the change of range. It accumulates changes of range even when the range rate is continually changing. A changing range rate is the *usual* situation.

Take the case where a target passes by own ship traveling a straight line course at a constant speed. Own ship is stationary.

Although target speed remains constant, the component along the line of sight, which is the whole range rate in this case, will gradually change from a negative rate through zero to a positive rate.

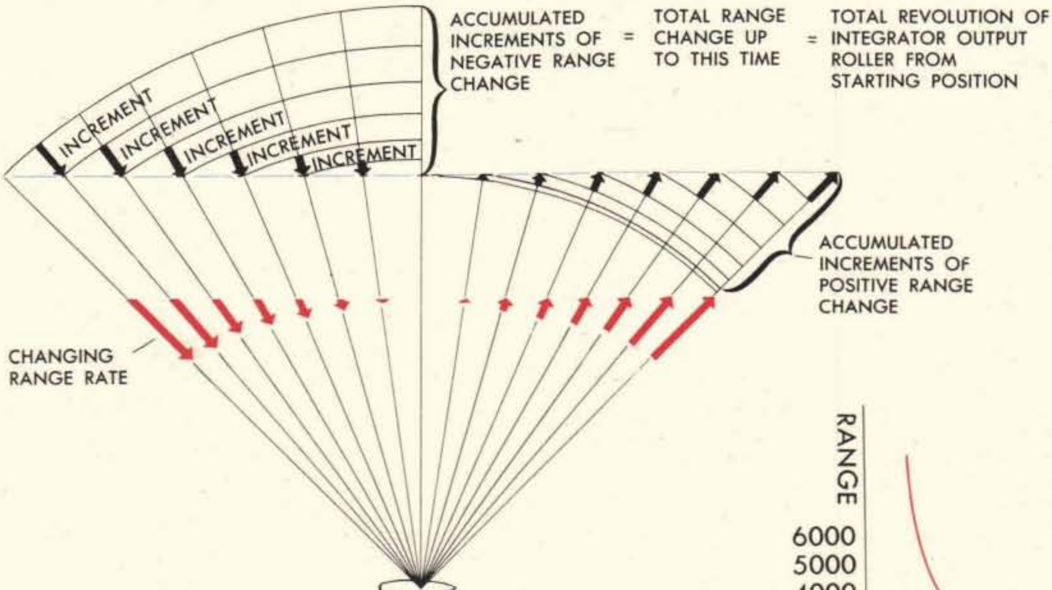


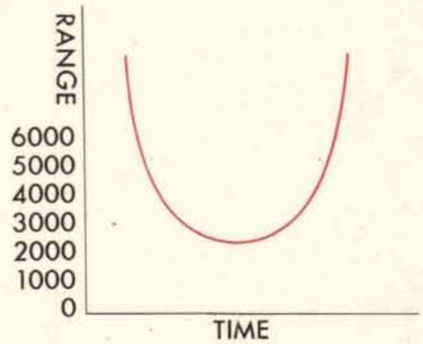


The range *rate* keeps changing as the target goes past own ship at a constant speed.

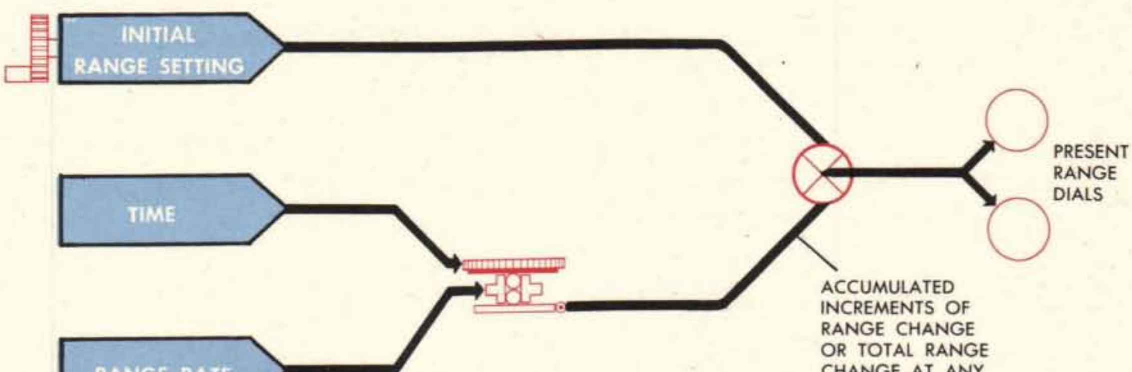
The integrator takes the range rate at a given instant and multiplies it by a small time interval. The computed change of range during that time is called an INCREMENT of range. The roller accumulates these increments by turning to new positions. Actually the increments do not accumulate as little jumps of the roller. The roller movement is as smooth as the changes in range rate.

changes





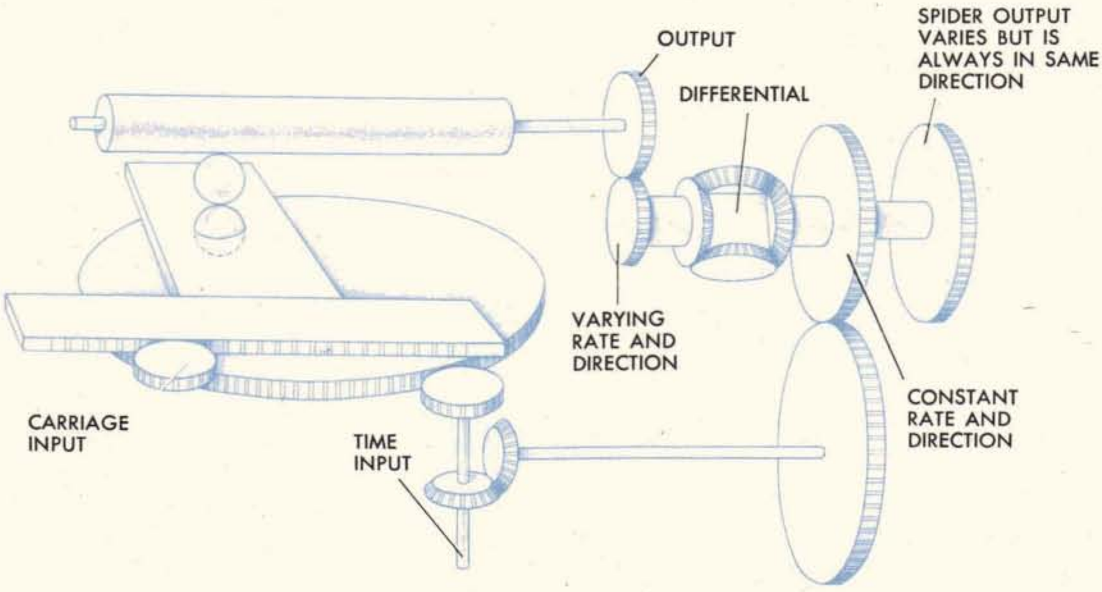
IF CHARTED, THE INTEGRATOR OUTPUT WOULD BE A SMOOTH CURVE—NOT A SERIES OF STRAIGHT LINES



Using the integrator to give an OUTPUT in only ONE direction

Sometimes the input and output of an integrator are values that can only be plus, never minus. In this case it would seem that only the plus half of the integrator disk could be used while the minus side would be wasted.

To avoid this waste, and to increase accuracy, a method of using the whole width of the disk for plus values has been worked out by adding a differential to the integrator output gearing.

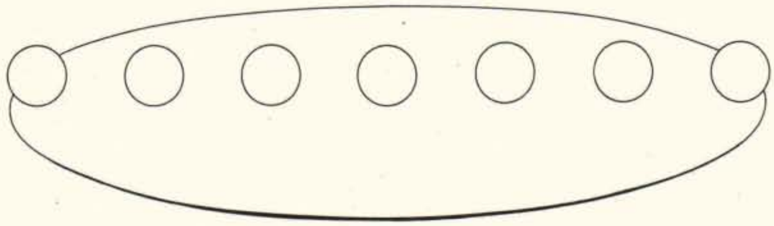


One side of the differential is driven by the output roller from the integrator. The other side is driven at a constant rate through a gear line by the time input.

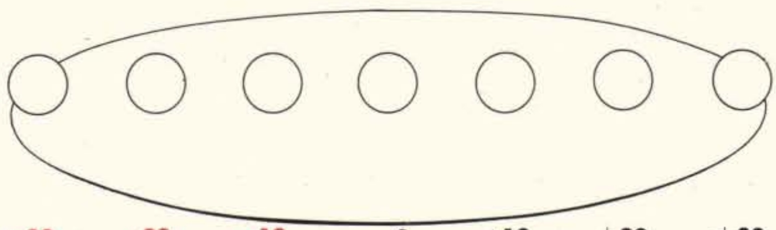
Assume that this constant rate from the time line is equal to the maximum plus rate of the output roller. With this setup, the carriage input can be set so that the zero value will position the balls at one edge of the plate, and the maximum input will bring them across to the other edge of the plate.

here's what happens

Suppose positions of the ball across the disk normally gave these output values ranging from minus 30 revolutions per minute to plus 30 revolutions per minute on the output roller.



If plus 30 revolutions are added per minute to each of these plus or minus outputs, the result will be a set of outputs running from zero to plus 60 instead of from minus 30 to plus 30.

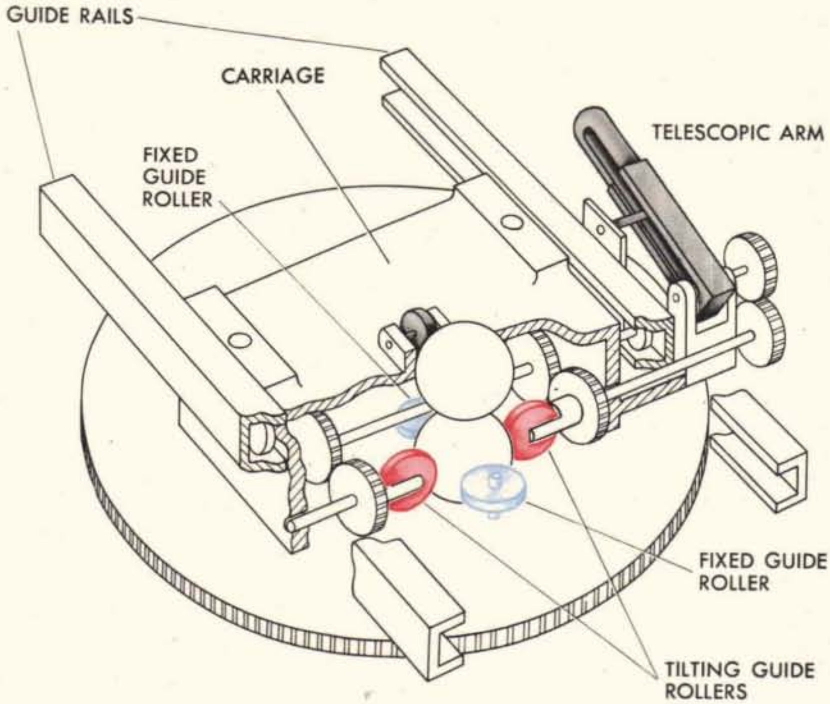


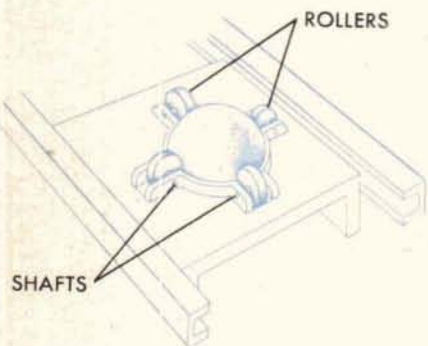
This is done in the differential by driving the second side at a speed equal to the maximum positive value of the output roller, and in the direction of the positive outputs from the roller.

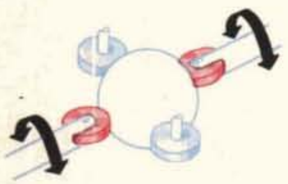
The outputs from the spider will now always be plus, whichever way the output roller is turning.

NOTE: For design reasons, the constant rate which is chosen is usually greater than the maximum plus rate of the output roller. Therefore, there is usually some positive movement of the output roller when the carriage is at its minimum position.

The GUIDE ROLLERS and







Each of the two balls is held in the carriage by four guide rollers. The guide rollers keep the balls positioned in the center of the carriage—yet allow them to roll. This arrangement enables the balls to do two things at the same time:

1. To move across the face of the rotating disk.
2. To deliver a smoothly changing output to the roller.

The TOP BALL guide rollers

The four top ball guide rollers are vertical and turn on shafts fixed to the carriage.

The BOTTOM BALL guide rollers

Two of the bottom ball guide rollers are fixed and horizontal. The other two rollers can be tilted.

When the ball is in the center of the disk all four rollers are horizontal. With the rollers horizontal the ball and disk can turn together and prevent the ball from wearing a hole in the center of the disk.

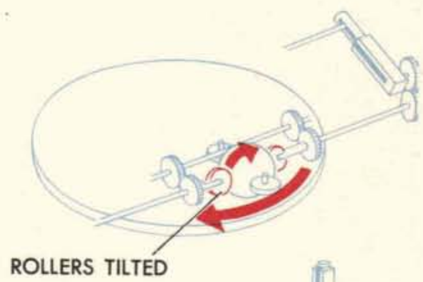
As the ball is moved away from the center of the disk, the telescopic arm turns the two tilting rollers from their horizontal position toward a vertical position.

the TELESCOPIC ARM

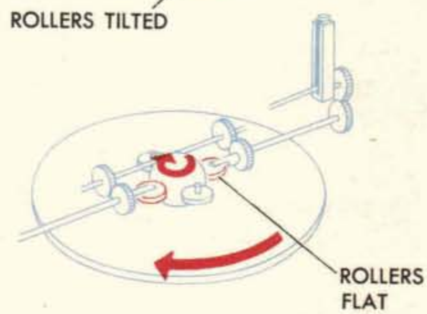
The telescopic arm tilts the movable guide rollers as the balls move away from the center of the disk.

The slotted bar inside the arm slides in and out at the top like a telescope. The slot rides on a pin fixed to the center of the back guide rail.

The angle made by the telescopic arm and the disk fixes the tilt of the movable guide rollers holding the bottom ball. The axis of the bottom ball is therefore always pointing toward the center of the disk.

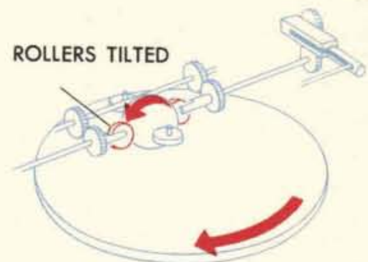


At one side of the disk the angle between arm and disk is small.



As the angle between the arm and the disk approaches 90° the balls are getting near the center of the disk.

When the balls are in dead center, the telescopic arm is at right angles to the disk. It holds the movable guide rollers so that their position matches the position of the stationary guide rollers. The bottom ball then turns WITH the disk. This keeps the ball from wearing a hole in the disk.

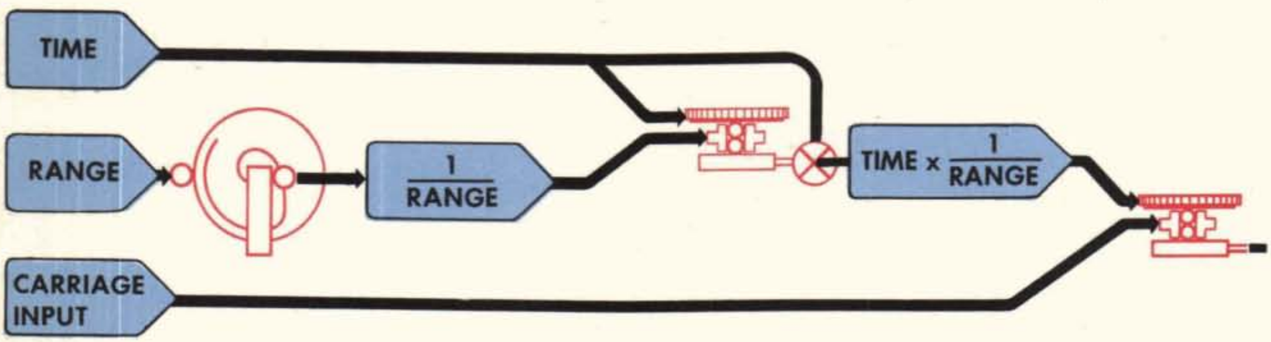


At the other side, the angle between arm and disk is small.

OTHER USES for the INTEGRATOR

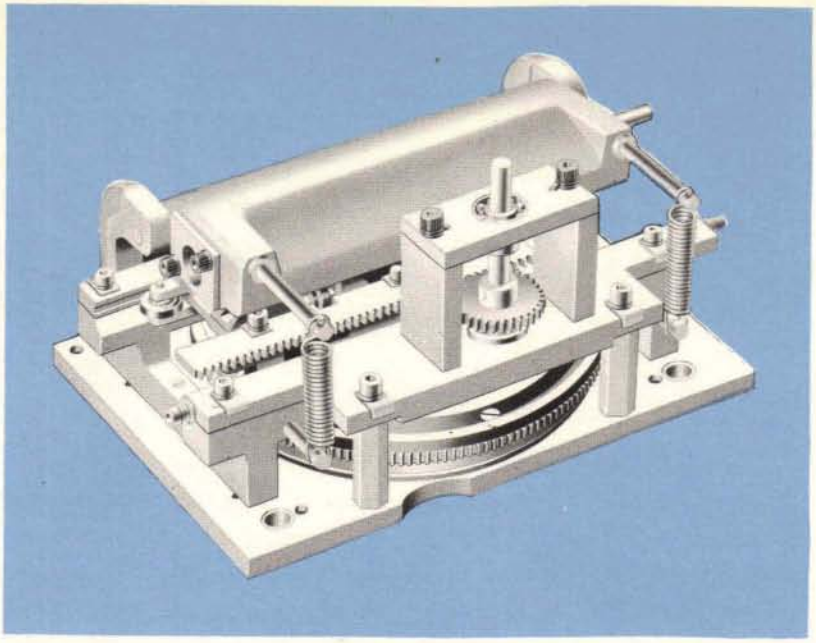
When an integrator is used to keep the range, the only input that varies is the range rate, which positions the carriage. The disk is turned at an unvarying speed representing the passage of time.

But the disk can also be used to represent a varying quantity, such as Time multiplied by the reciprocal of range. In such a case the varying input to the disk comes from another integrator. This other integrator has for its two inputs *time,* and *1/range* from a reciprocal cam.

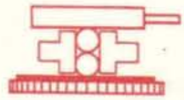


The output of the first integrator is fed into the disk of the second integrator. At high ranges the disk of the second integrator will turn more slowly. As range decreases it will turn faster.

These more complicated ways of hooking up integrators are explained in the computer OP's. It is enough here to know that the disk may turn at a varying speed representing one or more varying quantities.



The FOUR INCH integrator



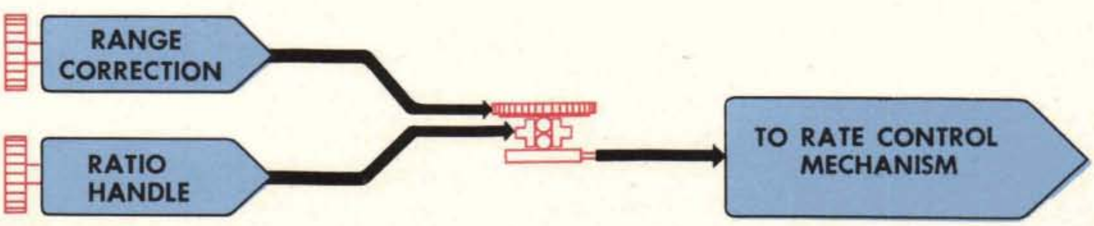
In addition to being smaller, this integrator differs from the five-inch integrator in several ways. The basic principle is the same.

1 The two springs holding the roller bracket of the four-inch integrator exert together only a 5½ pound pull compared with the 18½ pound pull of the two springs on the five-inch integrator.

2 On this account the output load which the four-inch integrator can drive without slippage between the balls and the roller is much smaller.

3 The lighter pressure reduces wear on the center of the disk to the extent that the tilted rollers are not needed.

The four-inch integrator is often used simply as a variable ratio gear. In one of the computer hook-ups it is used to vary the fraction of range correction which is fed into a rate control mechanism.



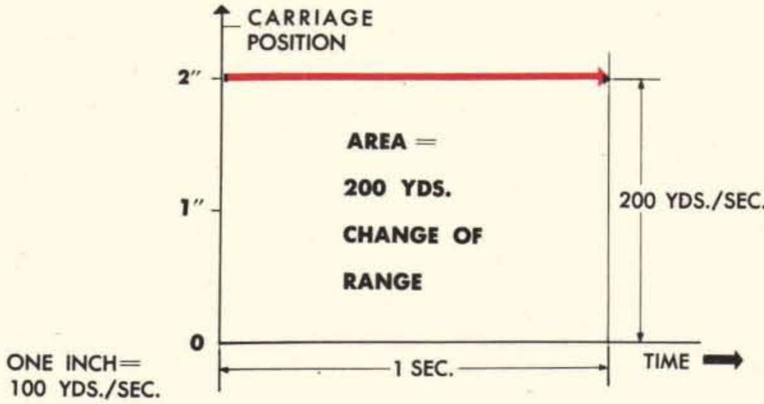
A more exact explanation of how an integrator handles a varying rate

Here is another more exact way of picturing what an integrator does when it keeps the Range.

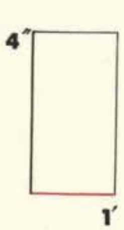
The output of a Range Integrator may be represented by the area of a rectangle. The height of the rectangle represents the distance of the carriage from the center of the disk, or the *Range Rate*. The base of the rectangle represents the amount of rotation of the disk, or the *Time*. The area of a rectangle equals the *height* × *the base*. The total change of Range equals the *Range Rate* × *Time*.

Because the height equals a given Range Rate and the base equals a given Time, the area of the rectangle formed by the height and the base *equals the total Range Change.*

For this example the carriage is held fixed 2″ away from the center of the disk for one second. If 1″ on the carriage equals 100 yards per second Range Rate, the output is 200 yards per second times one second, or 200 yards total Range Change.



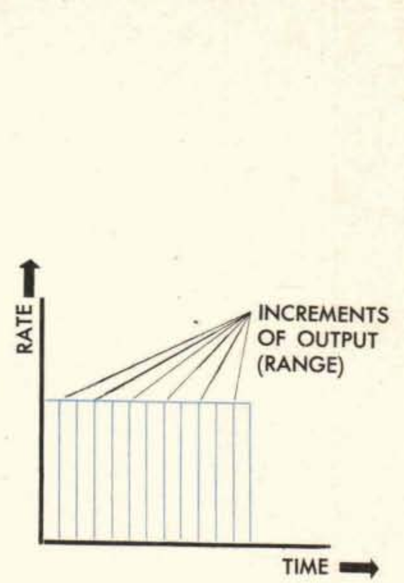
If the disk were to be turned for two seconds instead of one, the output would be twice at great. So would the area.



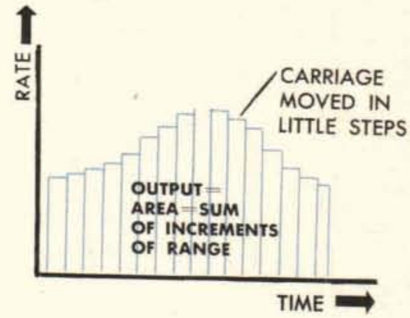
If the carriage were twice as far from the center throughout the time interval, the output would again be twice as great. So would the area.

This graphical interpretation of the output can be extended to explain how the output varies if the carriage is moving during the process.

We can think of the area of a rectangle as the sum of the areas of a large number of thin rectangles, as shown here.



Similarly, the area under a curve may be regarded as the sum of the area of an infinite number of infinitely thin rectangles. Each rectangle is as high as the curve at that point.

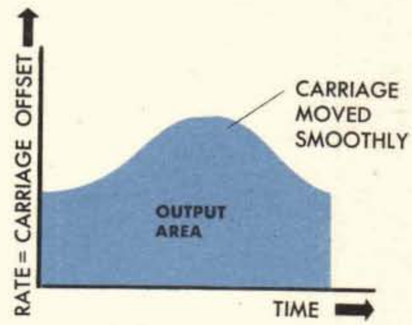


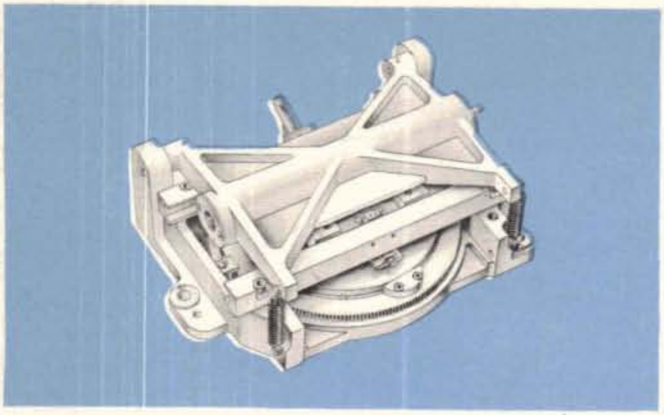
If the rectangles are thin enough, the sum of their areas will be *almost exactly* equal to the area under the curve.

Moreover, the disk type integrator adds up the outputs, by changing the output counter reading continuously.

Hence the integrator generates the area under a curve, if the height of the curve positions the carriage.

If range rate is put on the carriage, the integrator will therefore generate continuously "up to date" values of range, regardless of how range rate varies.





Setting the

The part of the Disk Integrator to be set is:

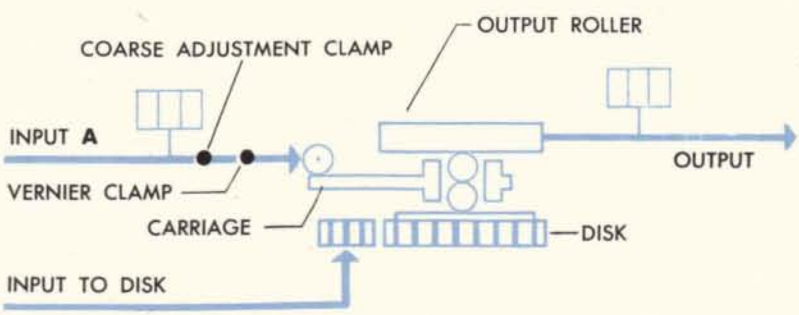
THE CARRIAGE

The parts which assist in the setting are:

1. The Disk
2. The coarse adjustment clamp.
3. The Vernier Clamp
4. The Output Roller

The *inputs* go to the Disk and the Carriage
The *output* comes off the Roller.

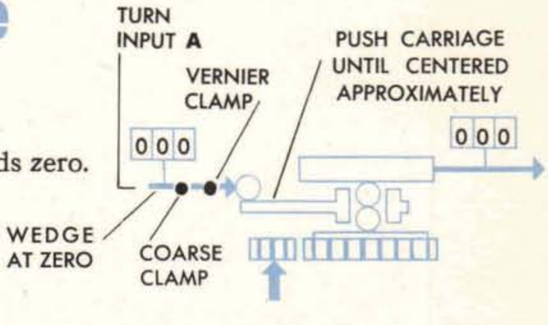
The carriage is positioned by input shaft "A" which also positions the counter. In setting the purpose is to join the carriage and the counter through the vernier clamp so that the position of the carriage is exactly indicated by the counter.



DISK INTEGRATOR

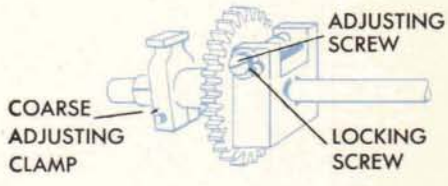
To set the carriage

1 Turn the input to the carriage until the counter reads zero. Wedge the input.



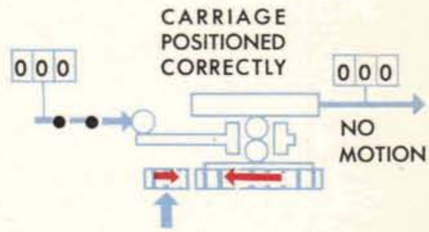
2 Slip-tighten the coarse adjustment clamp and push the carriage until it is approximately centered on the disk. This is the approximate zero position of the carriage. Tighten the coarse clamp.

3 To refine the setting, turn the adjusting nut of the vernier clamp to bring the carriage to the center of the plate.



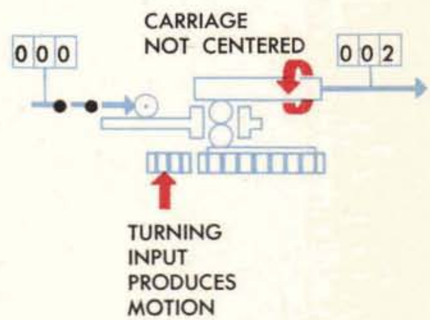
4 Check the setting by running the disk and adjusting the position of the carriage through the vernier clamp until there is no motion of the roller when the disk turns.

5 Here the carriage is centered exactly at its zero position. Turning the disk produces no motion of the output roller.



6 Here the carriage setting is incorrect. The carriage is not in the center of the plate. Turning the disk causes motion of the output roller.

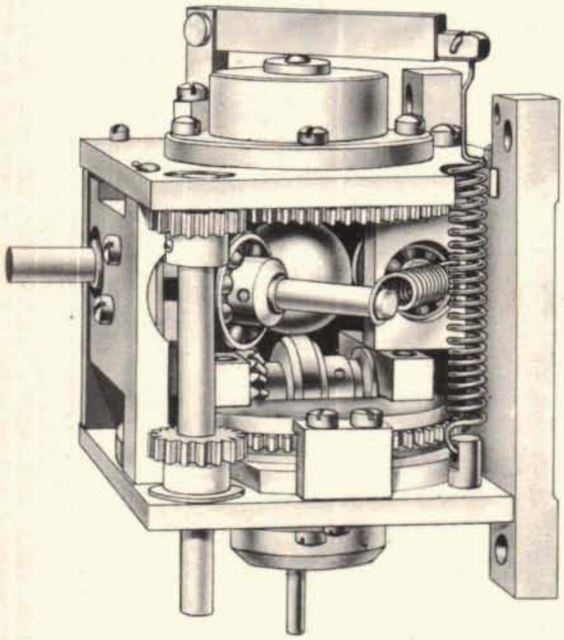
The rate at which the indicator counter moves represents the amount of error in setting.

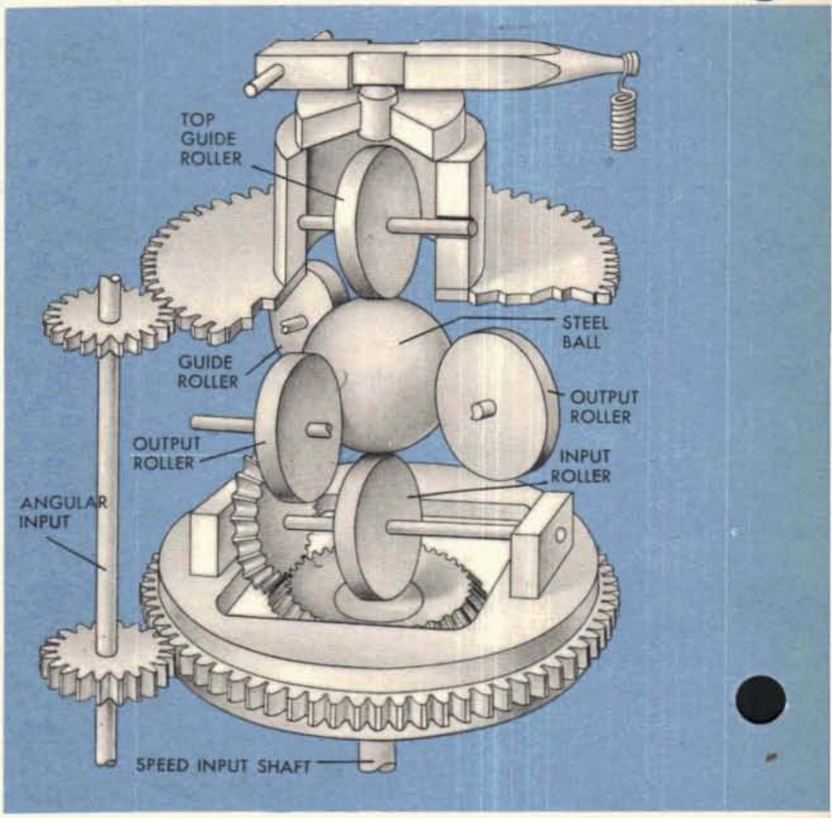


7 To correct this error repeat 3 and 4 until there is no motion on the indicator.

8 Tighten the locking screw in the vernier clamp. Be careful not to change the setting while tightening the locking screw.

The COMPONENT INTEGRATOR





The component integrator receives the increments of change of a vector's length and computes the increments of change of this vector's length in two directions, at right angles to each other. These increments are continuously accumulated as in the disk integrator.

There are two inputs to the component integrator. Usually one input is a changing linear value and the other input is a changing angular value.

1 One output would then be the product of the linear input and the **SINE** of the angular input.

2 The other output would be the product of the linear input and the **COSINE** of the angular input.

THE TWO INPUTS FORM A CONTINUALLY CHANGING VECTOR; THE OUTPUTS ARE THE CONTINUALLY CHANGING COMPONENTS OF THAT VECTOR.

The component integrator has one steel ball and five rollers. The ball is *driven* by the INPUT ROLLER mounted under the ball.

The ball itself *drives* two OUTPUT ROLLERS, which are mounted in the frame on horizontal shafts at right angles to each other.

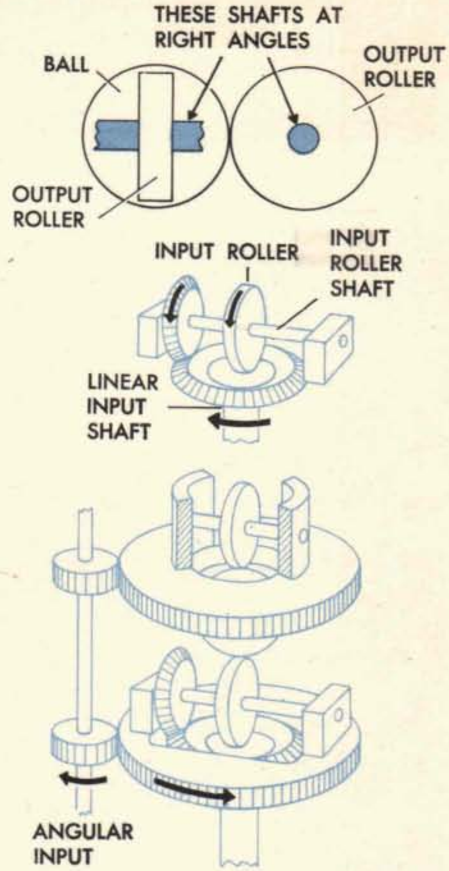
The other two rollers are GUIDE ROLLERS which hold the ball in firm contact with the input roller and the two output rollers.

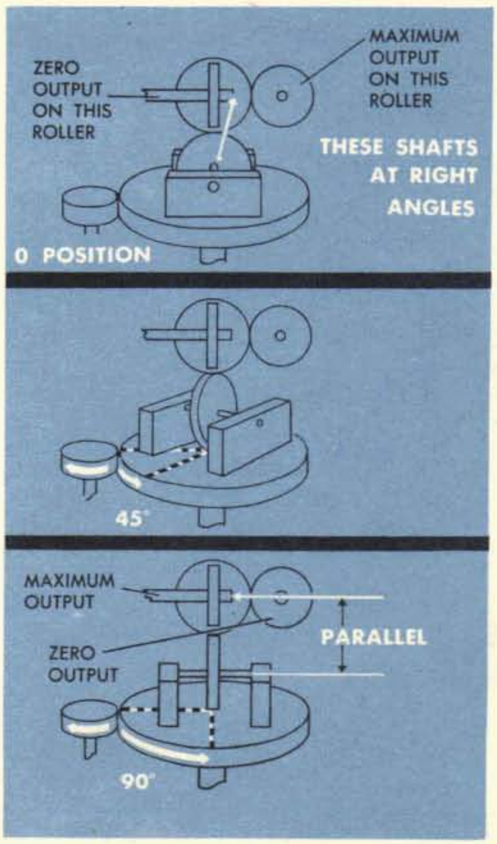
The ball and all five rollers usually have the same diameter.

The input roller is driven by the LINEAR INPUT shaft through a pair of bevel gears.

The ANGULAR INPUT drives the big spur gear on which the input rcller is mounted, so that the angular input controls the angular position of the input roller in relation to the two output rollers.

The angular input also turns the upper big spur gear on which one of the guide rollers is mounted, so that the axis of this roller is held parallel to the axis of the input roller.





Zero position for the angular input is with the input roller shaft at right angles to the shaft of either one of the output rollers, depending on the particular installation.

Here the angular input has turned the input roller 45° from its zero position.

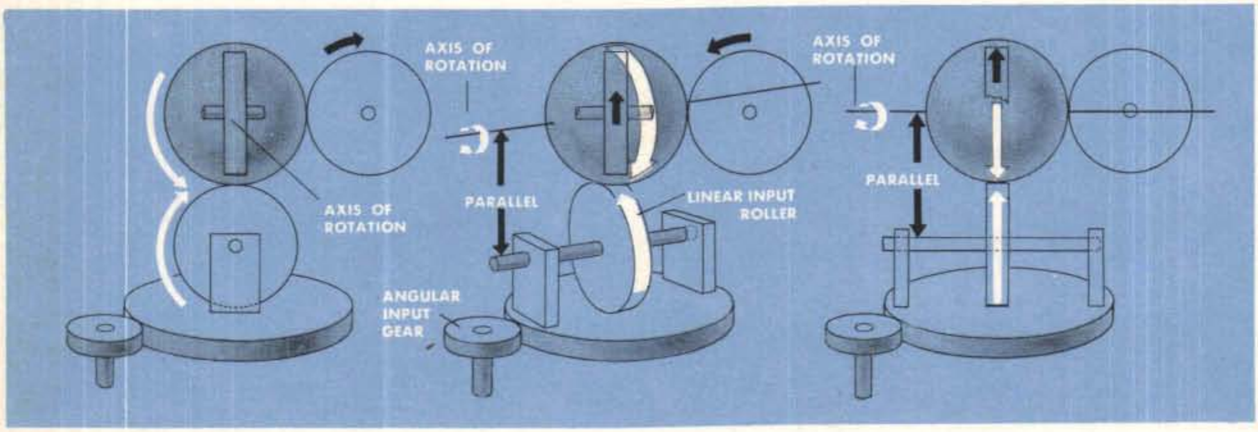
Here the angular input has turned the input roller 90° bringing the input roller shaft parallel to the shaft of the other output roller.

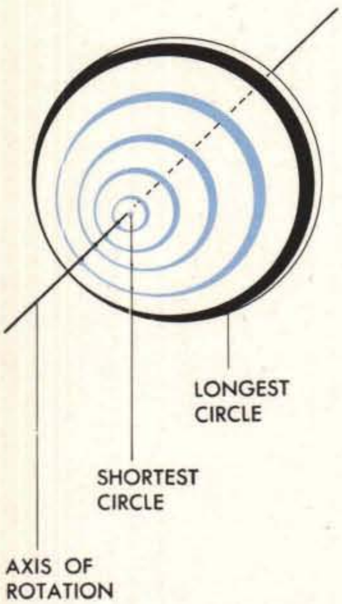
How the two inputs affect

The ANGULAR input gear turns the axis of rotation of the linear input roller.

This changes the axis of rotation of the ball in relation to the output rollers.

THE BALL ALWAYS TURNS AT THE SAME SPEED AS THE INPUT ROLLER. THE AXIS OF ROTATION OF THE BALL IS PARALLEL TO THE INPUT ROLLER SHAFT.





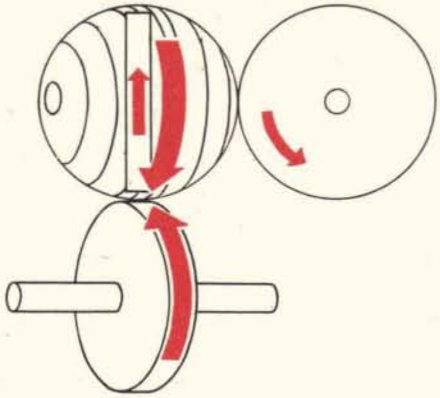
If lines are drawn around the ball at right angles to its axis of rotation, these lines will be circles of different sizes.

The largest circle is the circumference of the ball, and the smallest one is just a dot on the axis itself.

These circles actually represent the *distances* that points on the surface of the ball travel for each revolution of the ball.

Since each point moves in a circle when the ball makes one revolution, the speed of any point on the ball is proportional to the size of the circle on which that point lies.

the ball and output rollers



The point at which each output roller touches the ball lies on one of these circles.

This circle of contact represents the distance through which a point on that roller will travel during one revolution of the ball.

At different positions of the axis of rotation of the ball, circles of different sizes will touch the output rollers, so that the ROTATION OF THE ROLLERS will depend on the position of the AXIS OF ROTATION of the ball, as well as on the ball's rotation.

This becomes clearer if the ball and output rollers are viewed from above.

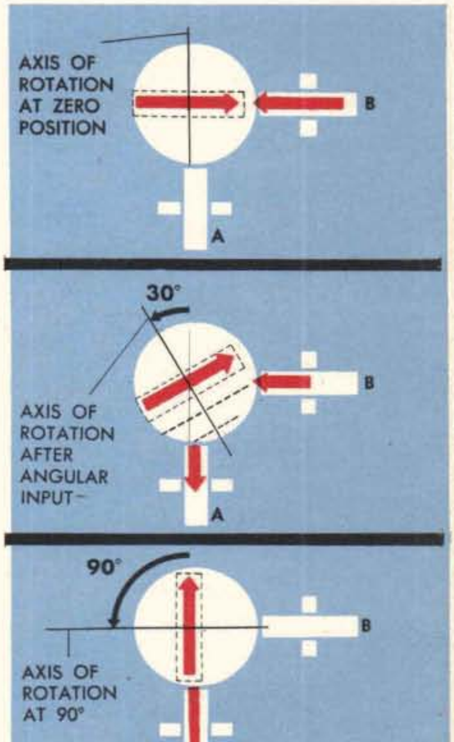
1 In zero position for output roller, *A*, the ball rotates on an axis at right angles to the shaft of output roller, *A*.

  Roller *A* touches the ball on the axis of rotation, and DOES NOT TURN AT ALL.

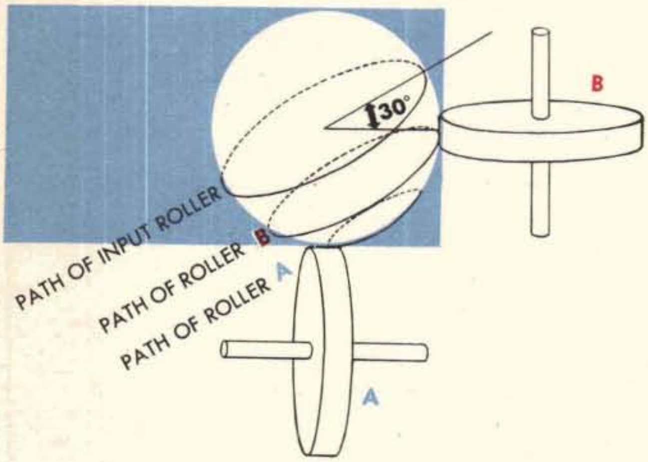
  Roller *B* is touching the biggest circle on the ball and turns at its maximum speed, equal to the speed of the input roller and the ball.

2 Here the angular input has moved the axis of rotation away from the zero position.
  Both rollers touch medium size circles and turn more slowly than the input roller and ball.

3 Here the angular input has moved the axis of rotation 90°.
  Roller *A* moves at maximum speed in this position.
  The roller *B* now touches the axis of rotation and doesn't move.



Finding out how much



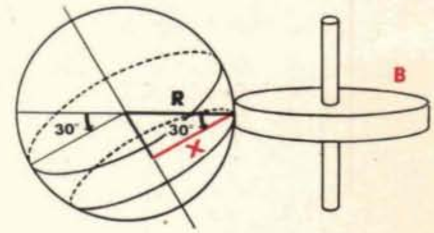
Suppose that the angular input is rotated from zero position through an angle of 30°, and that the input roller is then revolved one complete turn.

This sketch shows the paths on the ball which will be in contact with the rollers during this revolution of the input roller. The path of the input roller is the circumference of the ball itself; the other two paths are smaller circles.

The lengths of these smaller circles, compared with the circumference of the ball itself will show the relationship between the speed of the output rollers and the speed of the input roller.

For convenience, the RADII of these circles will be compared, since the radii are always proportional to the circumferences.

the OUTPUT rollers actually turn



Here X is the radius of the path of the output roller B.

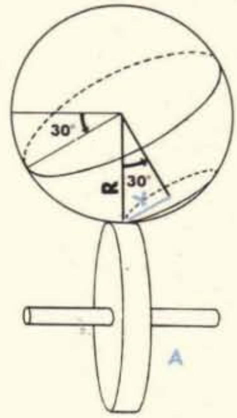
R is the radius of the ball itself, so it is equal to the radius of the path of the input roller.

In the triangle, $\frac{X}{R} = \cos 30°$

$X = R \cos 30°$

Since the ball and output roller have the same diameter, roller B turns cos 30° times one revolution for each revolution of the ball.

The ball travels at the speed of the input roller and 30° is the angular input. THE ROTATION OF OUTPUT ROLLER B EQUALS THE ROTATION OF THE INPUT ROLLER MULTIPLIED BY THE COSINE OF THE ANGULAR INPUT.



Here is the path of output roller A, with its radius marked Y.

In this triangle, $\frac{Y}{R} = \sin 30°$

$Y = R \sin 30°$

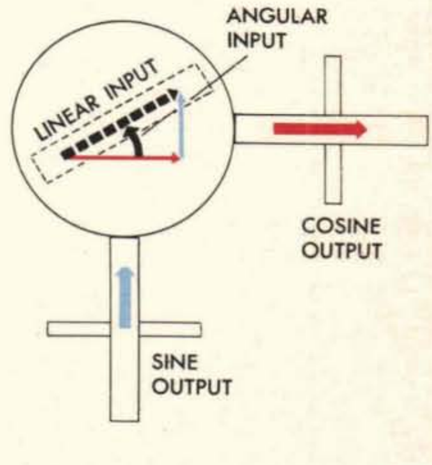
THIS OUTPUT ROLLER ROTATION EQUALS THE INPUT ROLLER ROTATION TIMES THE SINE OF THE ANGULAR INPUT.

The two output values are:

(1) Roller input × cos (input angle)

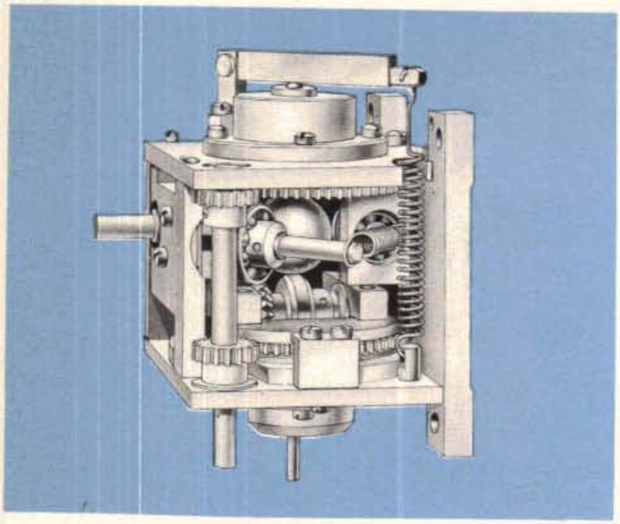
(2) Roller input × sin (input angle)

The two inputs can be drawn as a vector whose length is proportional to the ROTATION of the input roller. The two outputs are then components of that vector.



By changing the angular input, the component integrator may be used as a variable speed drive in which the output speeds are fractions of the input speed proportional to the sine and cosine of the angular input.

Setting the



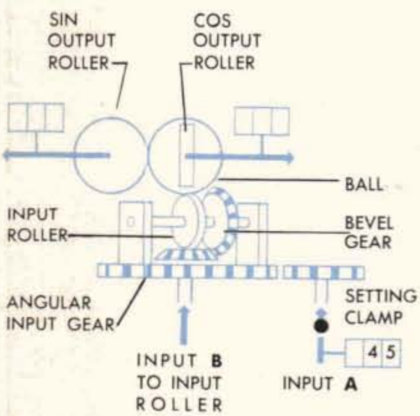
Only one of the Component Integrator's two inputs has to be set. This is the Angular Input Gear which receives the angular input. The parts which assist in the setting are:

The Input roller

The Output rollers

The *INPUTS* go to the Angular Input Gear and the Input roller.

The *OUTPUTS* come off the output rollers.



The input roller requires no setting because it is merely a driving roller.

The Angular Input Gear is positioned by input shaft *A*, which also positions a counter. The purpose, when setting, is to join the Angular Input Gear and the counter through the setting clamp so that the position of the Angular Input Gear is exactly indicated by the counter.

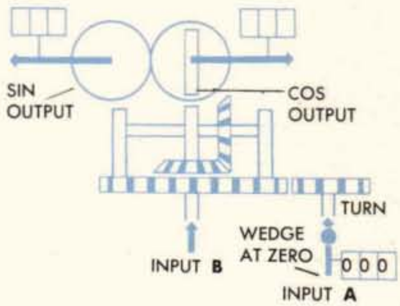
COMPONENT INTEGRATOR

To set the angular input gear

1 Turn the input *A* to the Angular Input Gear until the counter reads 0°. Wedge the input.

2 Turn the Angular Input until the input roller shaft is parallel to the cosine output roller shaft and the bevel gear on the input roller shaft is in the position described in the Computer's setting notes.

If the setting notes describe a setting for the input angle at 90° instead of zero, the roller shaft should be parallel to the *sine* output roller shaft.



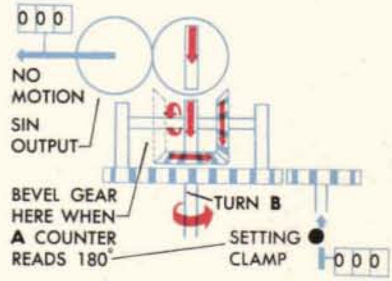
3 Slip-tighten the setting clamp.

4 Turn the roller input *B* and check the motion of the sine output. There should be no motion.

NOTE: The angle used in setting determines which output should be zero:

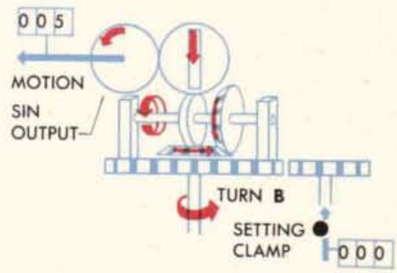
If the setting angle is 0° or 180° there should be no motion of the sine output roller. (Sin 0° or 180° = 0)

If the setting angle is 90° or 270° there should be no motion of the cosine output roller. (Cos 90° or 270° = 0)



5 Here the Angular Input is set correctly for 0°. When the input roller is turned there is *no* motion of the sine output.

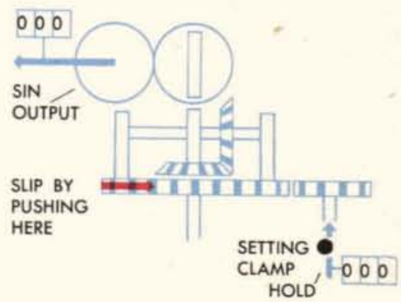
6 This setting is incorrect. The input roller is not quite parallel to the cosine output roller. Movement of the roller input causes motion of the sine output. The rate at which the indicator moves represents the amount of error in setting.



7 To correct this error, slip the angular input through the setting clamp until there is no motion of the sine output when the input roller is turned.

8 Tighten the setting clamp.

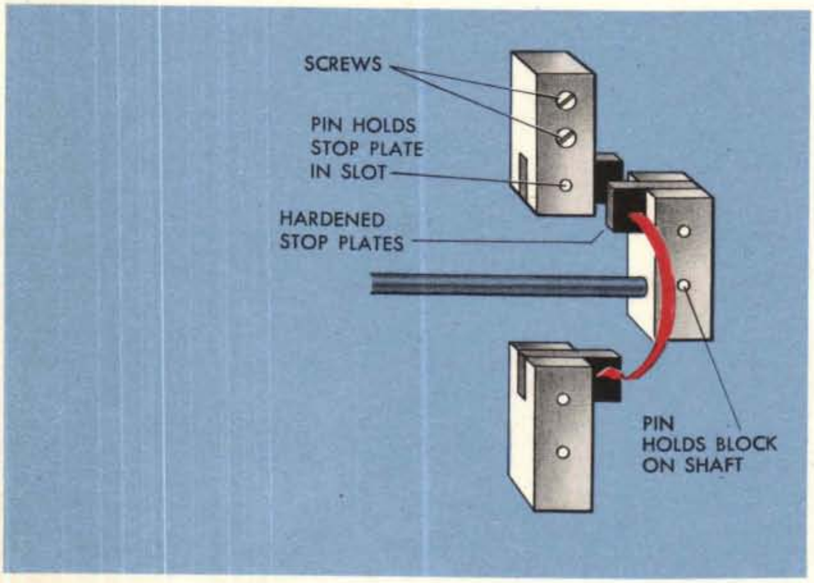
9 Remove the wedge.



NON-COMPUTING MECHANISMS

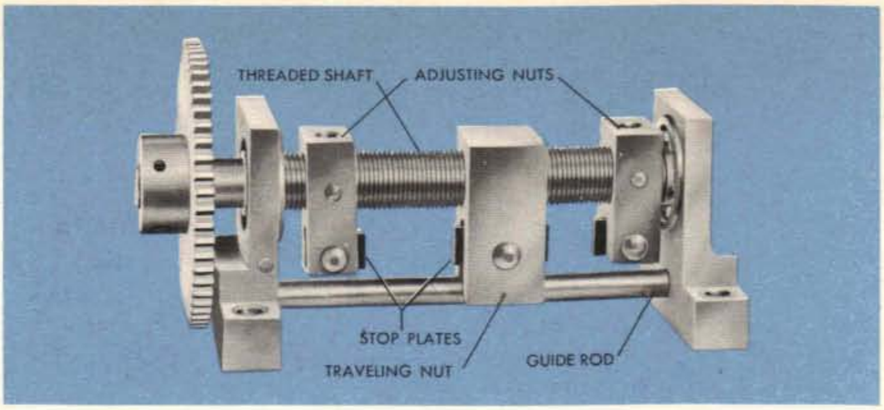
LIMIT STOPS

Limit stops are mechanical safety devices that prevent shafts from rotating farther than they should. They are used to keep hand cranks or electric motors from driving past the limits of the mechanisms to which they are connected. Limit stops protect cams, lead screws, input racks and integrator carriages.



Here is the simplest type

This limit stop permits a shaft to rotate only 180°. It consists of three metal blocks, with inserted steel stop plates. Two of the blocks are fastened to the framework of the machinery close to the shaft that is to be limited. The third block is pinned to the shaft. Every time the shaft makes a half turn in either direction, the stop plate on the block on the shaft touches the stop plate on one of the fixed blocks and prevents the shaft from rotating farther.



Here is the most usual type

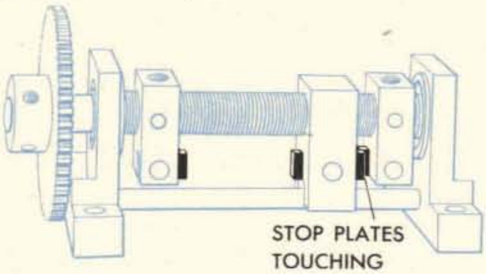
This limit stop consists of a traveling nut on a threaded screw, a guide rod to prevent the traveling nut from rotating, and two adjusting nuts. The adjusting nuts are pinned to the shaft on either side of the traveling nut and turn with the shaft.

The shaft is stopped from turning when the stop plate on one of the adjusting nuts hits against a stop plate on the traveling nut.

The distance between the adjusting nuts is accurately set before the stop is installed in the computer, to correspond with the exact number of revolutions the shaft can make before it must be stopped.

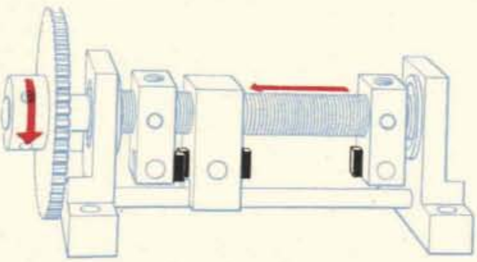
For example, a line is to be limited to 30 revolutions from its zero position:

When the line is at zero the traveling nut will be against one of the adjusting nuts.



After 30 revolutions of the line, the traveling nut will have traveled to the other adjusting nut, and will not be able to turn any farther.

AFTER 30 REVS.



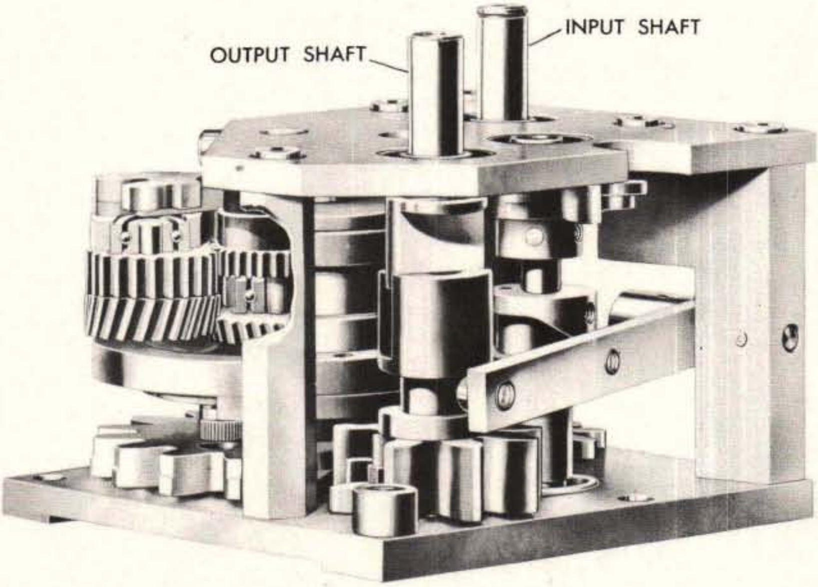
The INTERMITTENT DRIVE

Often in a computer several mechanisms with different limits of operation will be attached to the same line of gearing. For example, the present range line may turn from 0 to 35000 yards, but a reciprocal-of-present-range cam connected to that line may be cut to take values of range only from 750 to 22500 yards.

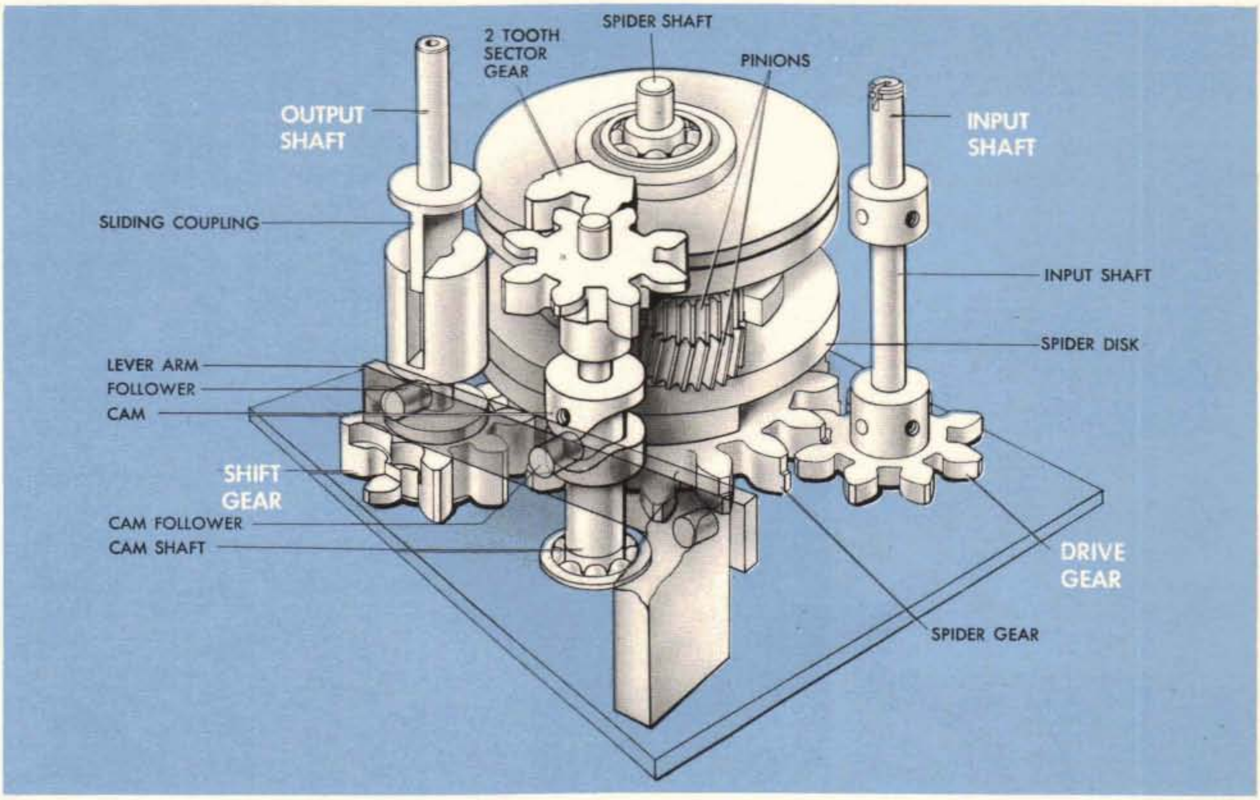
A mechanism is needed which will disconnect the range input to the cam at the instant the input line goes below 750 yards or above 22500 yards. The mechanism that fills this need is the Intermittent Drive.

In this example all values of range can turn the *input* to the Intermittent Drive, but only those values between 750 and 22500 will be transmitted to the cam. When the input line turns above or below these limits, the output gear will lock and stay locked until the values coming into the intermittent drive are again within the limits which the cam can handle.

Intermittent Drives are used in this way to connect and disconnect a variety of mechanisms including multipliers, component solvers and transmitters.



THIS IS THE SYMBOL FOR THE INTERMITTENT DRIVE



How the drive looks with the top plate off

On the bottom plate there are three spur gears, the drive gear, the spider gear, and the shift gear.

The drive gear drives the spider gear, which drives the shift gear.

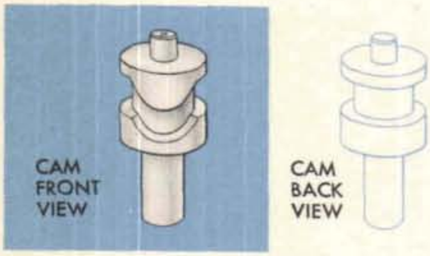
The disks and pinion gears on the spider shaft are there just to reduce the speed, so that the 2-tooth sector gear on the top will drive much more slowly than the spider gear.

The 2-tooth sector gear drives the gear on the cam shaft very slowly.

The cam lifts the lever arm up and down. At the end of the lever arm there is a small follower which fits into the groove on the shift gear. As the lever arm moves upwards it slides the shift gear up along the output shaft, out of mesh with the spider gear.

That's how the intermittent "cuts out." The input can keep on turning after this, but the shift gear will not be meshed, and it will not turn.

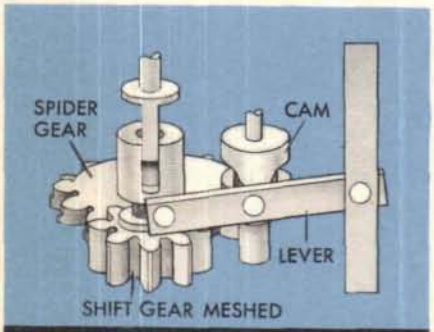
The CAM



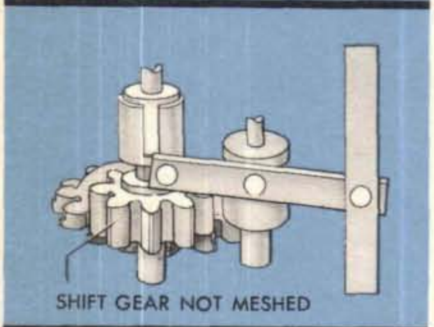
In the intermittent drive the shift gear stays IN mesh for a certain number of revolutions of the drive gear and then moves up OUT of mesh.

The number of revolutions the shift gear stays in mesh is CONTROLLED BY THE CAM AND GEARING.

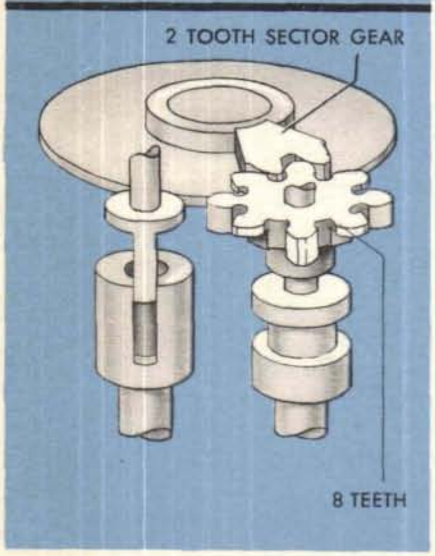
The cam is really a collar with a groove in it.



The groove is low for $\frac{1}{4}$ of the distance around the collar, and while the lever pin is in this low part, the shift gear meshes with the spider gear.



When the follower is not in this low part of the groove, the lever arm slides the shift gear up its shaft out of mesh.



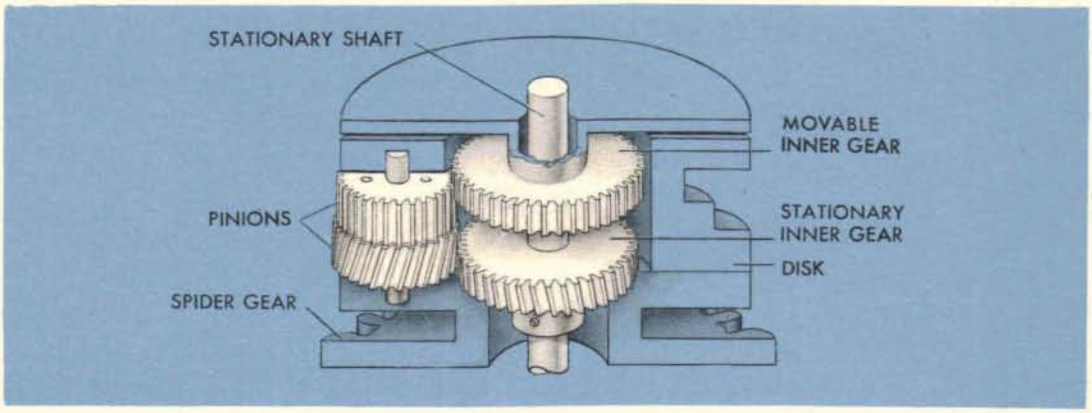
The gear on the top of the cam shaft has 8 teeth, so it will be turned $\frac{1}{4}$ revolution for each revolution of the 2-tooth sector gear which drives it.

Since the shift gear is IN mesh for only $\frac{1}{4}$ turn of the cam shaft, the cam will hold the shift gear IN mesh for only ONE revolution of the 2-tooth sector gear.

Obviously, the shift gear must stay in mesh for MANY revolutions of the DRIVE gear, so there has to be a great reduction in speed between the revolutions of the INPUT SHAFT and the revolutions of the 2-TOOTH SECTOR GEAR.

The planetary gearing above the spider gear takes care of this reduction. It gives a ratio of 1 to 29 so that the shift gear will stay meshed for 29 revolutions of the drive gear.

and the PLANETARY GEARING



As the drive gear turns the spider gear, the two pinions of the planetary reduction gearing are carried around on the disk which is screwed to the spider gear.

While being carried around, the two pinion gears rotate on their own shaft.

These pinions are fastened to each other. They mesh with the two inner gears on the stationary shaft, which are housed inside the casing between the disks.

The two pinions have the same number of teeth, but the MOVABLE inner gear has 2 more teeth than the STATIONARY inner gear. As the pinions are carried around, the lower one rolls on the stationary inner gear.

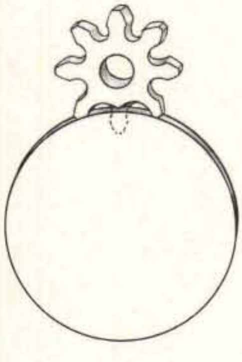
Since the upper pinion is fixed to the lower pinion it turns at the same rate as the lower one, and meshes with the movable inner gear.

BUT AS THE MOVABLE INNER GEAR HAS THE TWO EXTRA TEETH IT WILL BE DRIVEN AROUND AN AMOUNT EQUAL TO TWO OF ITS TEETH FOR EACH WHOLE REVOLUTION OF THE SPIDER GEAR.

Accordingly, this movable inner gear turns very slowly.

The disk carryng the 2-tooth sector gear is fastened to this movable inner gear. The 2-tooth sector gear will also turn very slowly compared to the spider gear.

In fact, it turns once for 14½ revolutions of the spider gear, or 29 revolutions of the input gear.



LOCKING the SHIFT GEAR

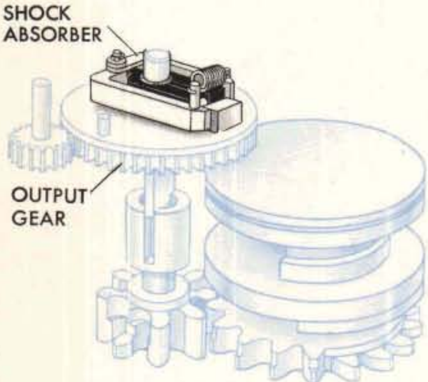
As soon as the shift gear slides out of mesh, it must be locked.

If it were free to turn, the input and output lines might not be synchronized when the output cuts in again.

To make the gear lock, one tooth is partly cut away or "mutilated."

When the gear is raised, the teeth on either side of the mutilated tooth are held against the side of the spider disk, so that the gear cannot turn. The mutilated tooth fits under the edge of the disk. In this position the gear cannot turn and the output is locked.

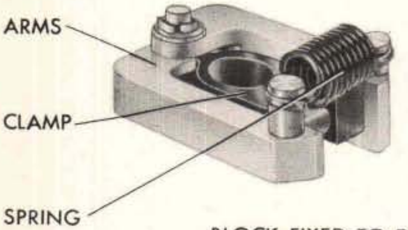
The SHOCK ABSORBER



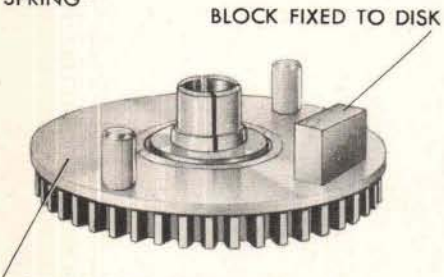
When the cam brings the shift gear down into mesh with the spider gear, the spider gear may be turning rapidly.

The sudden starting of the output shaft could cause damage to the gearing on the output line. To prevent this there is a gear with a shock absorber on the output shaft.

In the shock absorber a disk is fastened to the output gear and both the gear and disk turn freely on a hub on the output shaft. The hub is held tightly to the shaft by a special clamp. Two arms are pivoted on one end of the clamp and are held against the other clamp end by a spring. The two arms straddle a stop block fastened to the gear disk. The shaft motion is transmitted through the clamp assembly and the spring to the stop block on the gear disk, causing the gear to turn as the shaft is turned.



A sudden shaft movement in either direction forces one of the arms away from the stop block and stretches the spring. The spring pressure exerted against the arm remaining in contact with the stop block starts the gear turning and continues to turn the gear until the shaft and gear regain their original position with both the arms touching the stop block. The spring, by stretching, absorbs the first shock of movement and allows the gear sufficient time to pick up speed and so prevent damage to the lines it drives.



THE FIRST MOVEMENT OF SHAFT STRETCHES THE SPRING

THEN THE GEAR AND SHOCK ABSORBER ROTATE TOGETHER

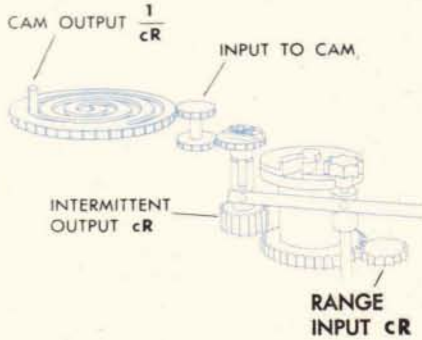
Here's an INTERMITTENT DRIVE in action

An intermittent drive on the range line controls the inputs to the $1/cR$ cam.

This cam calculates the reciprocal of range:

The reciprocal cam may be cut to take range values between 750 yards and 22500 yards only; and the intermittent is connected to the cam input to keep out all other values.

In order to make this clear, consider what happens when a target flies right over own ship:



NOTE:
In the diagrams below, the locking gear has been omitted.

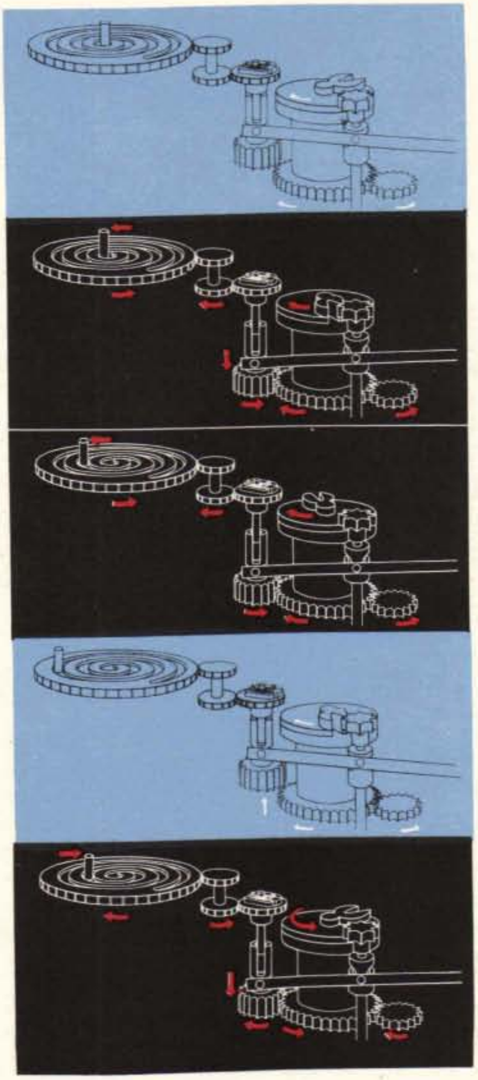
The range input is turning as range decreases. The output is "cut out" and does not drive the $1/cR$ cam. The $1/cR$ cam follower is near the center of the cam.

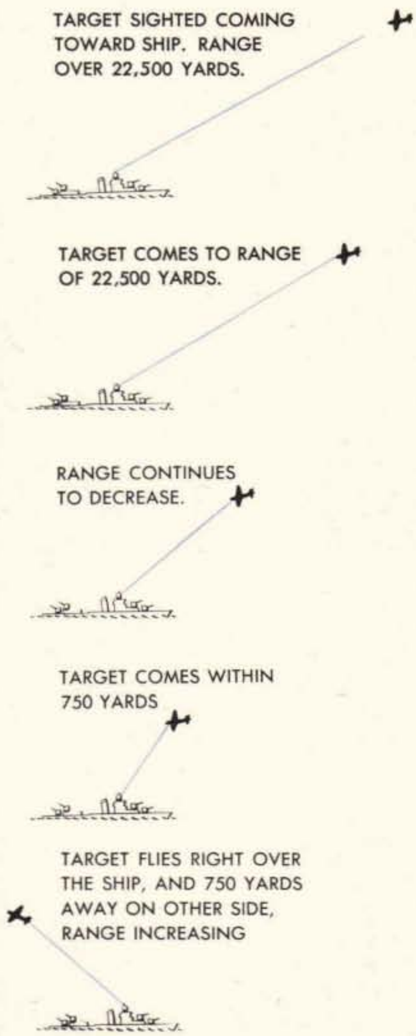
The sector gear turns the "cut-out" cam. The output gear "cuts in." The $1/cR$ cam begins to turn.

All the input values of cR drive through the intermittent to the $1/cR$ cam.

The sector gear has made one complete revolution and now turns the "cut-out" cam again. The output "cuts out" and stops driving the $1/cR$ cam. The $1/cR$ cam follower is at the outside end of the cam groove.

The range input is turning in the other direction as range increases. The sector gear turns the cam back, and the output "cuts in" again and drives the $1/cR$ cam in the opposite direction.





HAND CRANKS

HERE ARE TYPICAL HANDCRANKS

Hand cranks are used as a means of putting values into the computer by hand. They are used to turn lines of gearing which put inputs into various mechanisms.

In some cases a hand crank is the only means by which a quantity is put into a computer. This is true of wind speed, and wind direction.

More often a hand crank is an alternative method of introducing an input when the normal automatic receivers fail, or for some other reason are out of use.

Some of the hand cranks are used mainly as a convenient way to hold certain inputs or outputs at a given value for running tests.

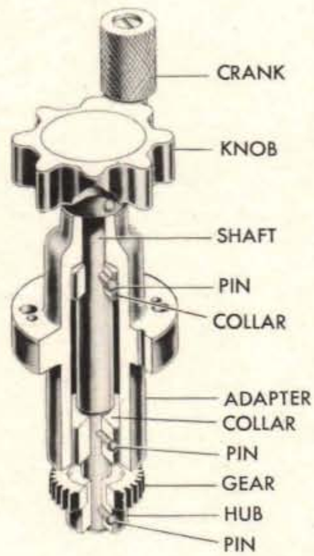
The hand cranks on computers are usually just taken for granted as parts of the covers on which they are mounted. Actually they are themselves important mechanisms requiring care in operation and upkeep.

Here's a simple hand crank

This hand crank consists of a shaft with a knob pinned to one end and a gear pinned to the other.

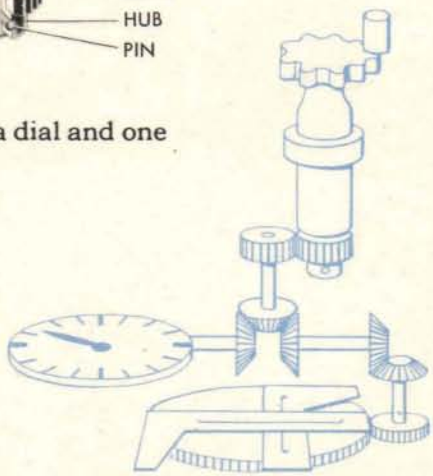
The knob has a crank so that inputs can be cranked in quickly and easily.

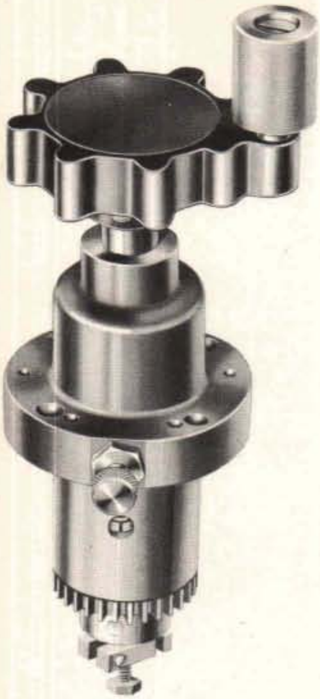
The shaft is mounted in an adapter which is screwed onto the cover of the computer.



This is how the hand crank looks inside.

Here is an example of a hand crank that positions a dial and one of the inputs to a component solver.





What HAND CRANKS can do

Various devices can be added to the simple hand crank to enable it to do other jobs. Different handles have different combinations of these devices according to the work they have to do.

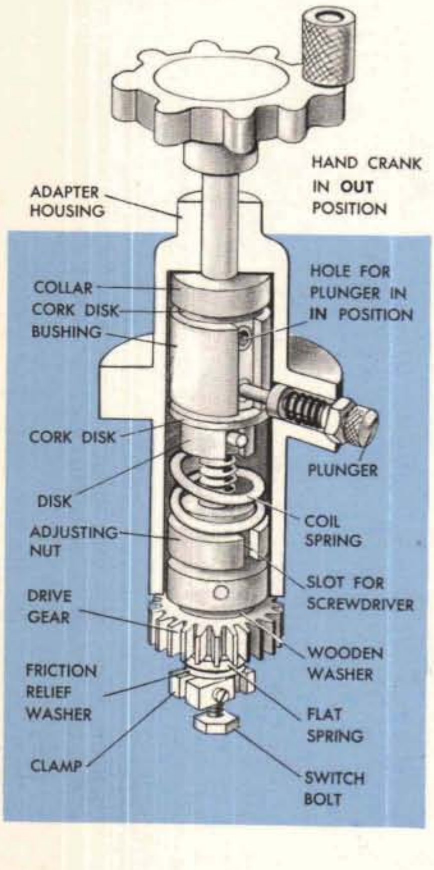
Here's a handle with all the common devices. It has:

Adjustable Holding Friction

Adjustable Friction Relief Drive

Plunger with a locking device to hold the handle in position

Adjustable Push Button Switch-Bolt



The frictions

The HOLDING FRICTION is a friction created by pressure exerted against two cork disks by a collar, a bushing and a metal disk. This friction puts a drag on the hand crank. This keeps the hand crank positioned and thus prevents motion from backing out through the hand crank.

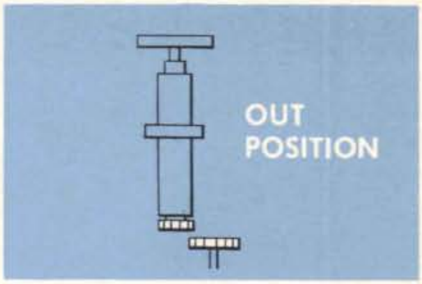
The drive gear is held to the shaft by the FRICTION RELIEF DRIVE consisting of a flat spring, a wooden washer, and a clamp. If the line hits the end of a limit stop or the torque on the line is too great, the friction will slip so that the gearing and mechanisms will not be damaged.

The plunger for changing position of the shaft

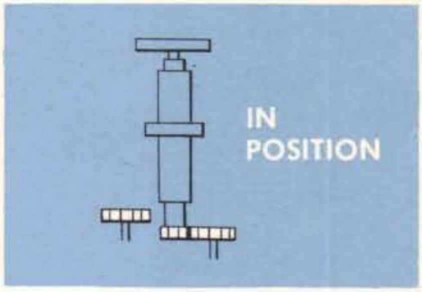
The hand crank usually has two positions: the IN position and the OUT position. In changing position, the shaft and drive gear move in relation to the adapter housing. A plunger is used to hold the shaft in either of these two positions. The plunger is pulled out and the hand crank is pushed or pulled to its new position. The plunger is returned by a spring when released.

in addition to cranking

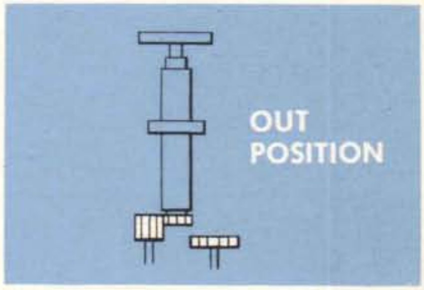
A hand crank may SHIFT GEARS.



With this hand crank in the OUT position, the crank gear is disengaged. When the hand crank is in its IN position, the crank gear meshes with a line of gearing.



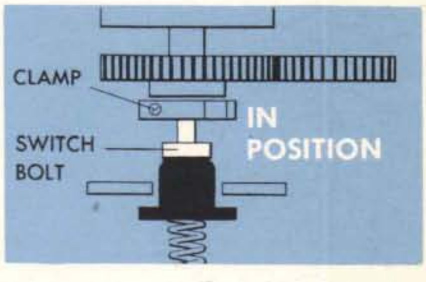
This crank gear is set between two other gears. With the shaft in its IN position, the gear is meshed with one gear. In its OUT position it disengages the first gear and meshes with the second gear.



The gear as attached to this hand crank is set between two gears. One of these gears is wide and is always meshed with the gear on the hand crank. In the OUT position the crank gear engages only the wide faced gear.

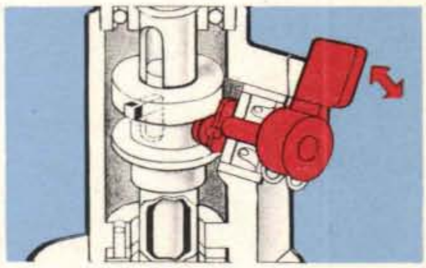
In the IN position the shaft is lowered. The crank gear engages the two gears at once so that the data goes to two mechanisms at the same time.

A hand crank may push SWITCH BUTTONS by changing the position of its shaft.



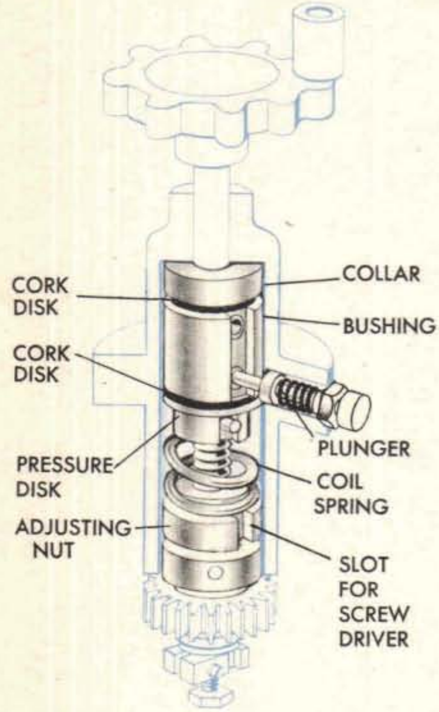
In the OUT position the crank gear is disengaged; the circuit is closed and a follow-up motor or receiver controls the line.

In the IN position the SWITCH BOLT below the gear depresses a push button switch and breaks an electric circuit, usually to de-energize a servo motor. The gear is meshed with a line of gearing and the data is set in by HAND.



In cases where a hand crank is shifted frequently a more convenient method of moving the hand crank from one position to another is needed. A shift lever can be used instead of the plunger and pin. The shift lever mechanism both moves the hand crank and holds it in position once it has been moved.

Details of HAND CRANK FRICTIONS



Holding Frictions

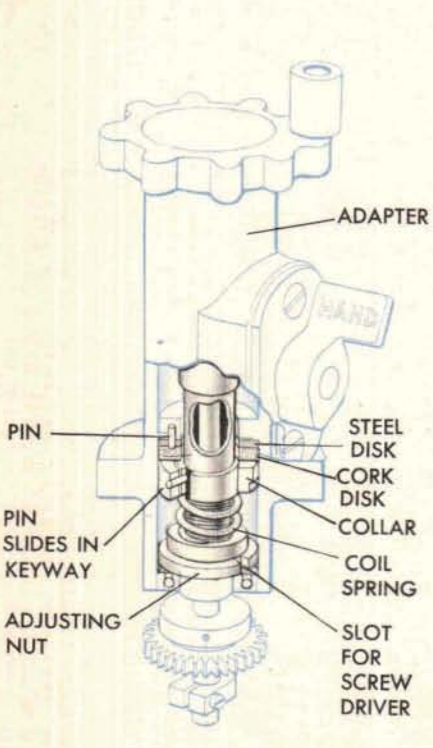
Here is one type of holding friction used on a hand crank:

It consists of a metal bushing that turns freely on the shaft. A plunger prevents the bushing from turning with the shaft. There is a cork disk cemented to each end of the bushing. A coil spring holds the collar and pressure disk tightly against the cork disks.

The tension of the spring against the pressure disk is regulated by turning the adjusting nut.

The friction is adjusted until it is great enough to prevent the value from backing out through the hand crank.

To move the hand crank, the turning force has to be strong enough to overcome the friction between the stationary cork disks and the collar and pressure disk that turn with the shaft.



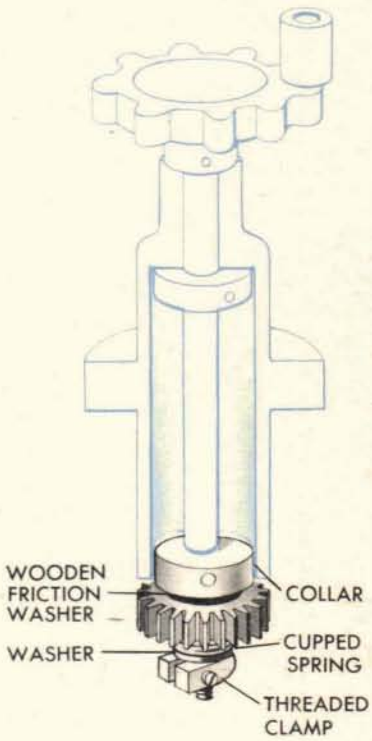
This is another type of holding friction used on hand cranks.

It consists of a cork friction inside an adapter.

There is an adjusting nut which can be screwed up and down on a thread. This nut compresses a spring which bears against a collar. The collar can move up or down and turns with the shaft by means of a pin which slides in a keyway. The collar presses on a cork disk. The cork disk is cemented to a steel disk which is pinned to the adapter.

Turning the adjusting nut either releases or compresses the coil spring increasing or decreasing the friction between the rotating collar and the stationary cork disk.

The friction relief drive

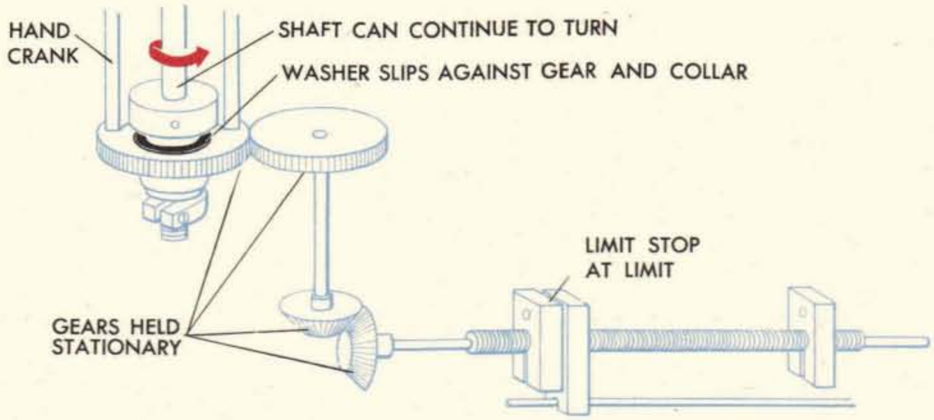


On this type of friction drive a wood washer is used.

The gear can rotate on the shaft. A collar is fastened to the shaft and the wooden washer inserted between the collar and the gear. A cupped spring pressing against the other side of the gear creates a friction between the collar, wooden washer and gear. The tension of the cupped spring is regulated by screwing a clamp along the threaded shaft.

When the crank is turned, the collar turns with the shaft, and the friction drive will turn the gear with the collar and shaft. If there is an overload, or the shaft line is stopped by a limit stop, exerting additional force on the hand crank will cause the friction drive to slip. The shaft and collar turn, but the gear remains stationary.

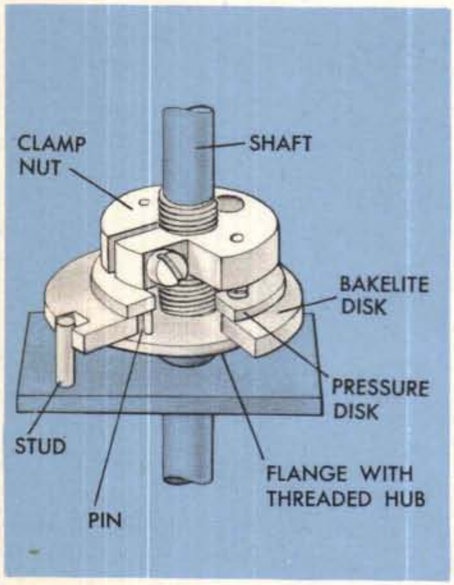
In this way the hand crank and the gearing connected to it are protected when the line runs into a limit stop.



HOLDING FRICTIONS

A Holding Friction holds a shaft. That is, it exerts a drag on a shaft so that a force greater than the drag has to be used before the shaft can turn.

This friction drag prevents shaft values from backing out. It also stops oscillations.



Here is one type

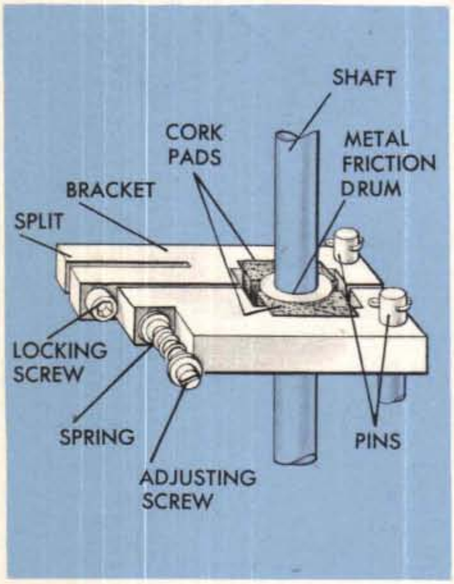
In this type, friction is created between the shaft and a bakelite disk that is held stationary.

A flange with a threaded hub is pinned on the shaft. A bakelite friction disk, which is held stationary by a stud, is held against the flange by a pressure disk. The pressure disk has two pins that fit into the flange, so that the pressure disk is driven by the hub. Two springs between this disk and a clamp nut hold the flange and pressure disk against the bakelite disk.

The springs push against the pressure disk, and create friction between the pressure disk and flange, which turn with the shaft, and the bakelite disk, which is held stationary.

The amount of friction is controlled by turning the clamp nut to change the spring pressure.

After the proper pressure is applied to the friction disk, the screw in the clamp nut is tightened. This holds the clamp nut so that it cannot turn.



Here is a second type

This type consists of two cork-lined metal brackets which press against a metal drum pinned to the shaft. These brackets hinge on two fixed pins in the base plate.

Turning the adjusting screw compresses or releases a spring; the spring pressure presses the brackets together causing the cork pads to press against the friction drum, creating friction between the shaft and the two stationary brackets.

There is a slot and locking screw in one of the brackets. Tightening the locking screw clamps the adjusting screw to prevent it from turning after the spring pressure is adjusted.

To turn the shaft a force has to be strong enough to overcome the friction between the cork-lined brackets and the drum on the shaft.

A DAMPING friction similar in principle to the one illustrated, can be used to reduce oscillation.

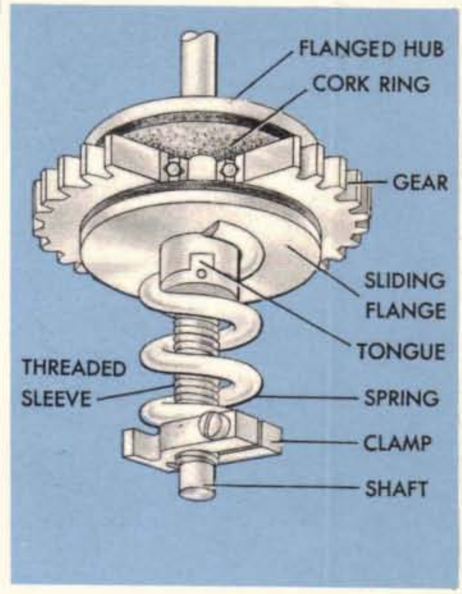
DRIVING FRICTIONS

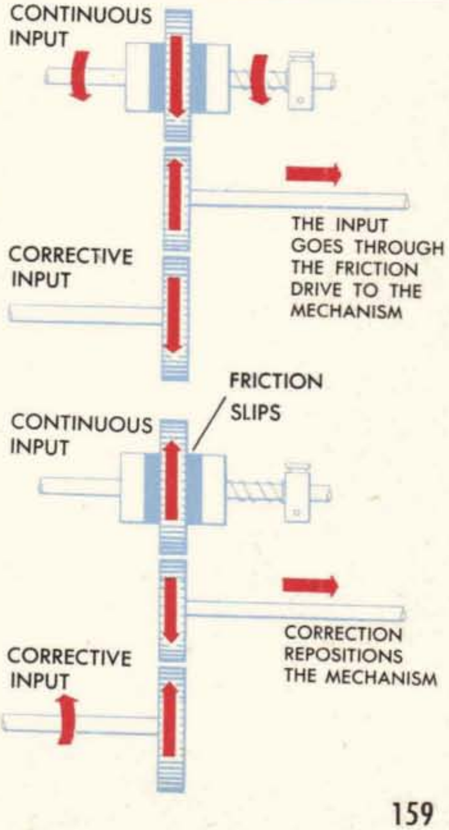
Driving frictions described elsewhere are used to take up shock and to prevent damage. For instance, when a motor overruns enough for the output to hit a limit stop, or when a handcrank is turned with too much force, or when the line driven by the crank has hit a limit and the crank is still turned, the driving friction slips and eases the strain on the mechanism.

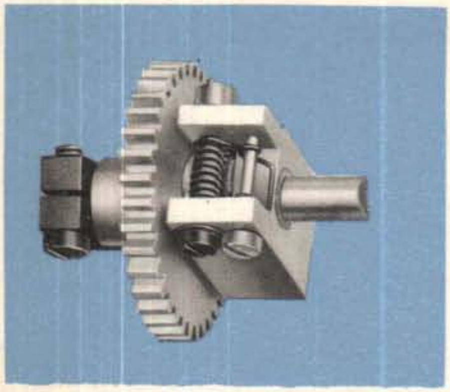
A driving friction can also be used to alter the value of a continuously changing shaft line. The parts of this type of driving friction are arranged as follows:

A flanged hub is pinned to the shaft. Then a gear with cork washers cemented to both sides is mounted on a ball bearing to turn freely on the shaft. A sliding flange is added which slides on the shaft and bears against one cork ring. This flange is turned with the shaft by a tongue which is part of a collar pinned to the shaft. A spring is compressed between the flange and a clamp. The clamp screws on a threaded sleeve and controls the spring pressure.

The continuous input turns one of the shafts in a shaft line to a computing mechanism. The input normally drives through the friction to position the shaft line. By slipping through the friction drive, a correction can be made by repositioning the shaft line without disturbing the input. After the correction has been made the input will again turn the shaft line.



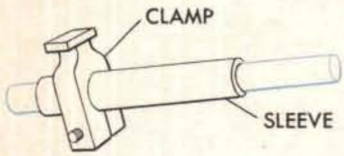




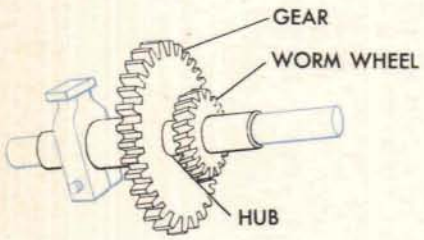
The VERNIER CLAMP

The vernier clamp is used to make a fine adjustment in the position of a gear on a shaft. With the vernier, the gear can be turned very small amounts relative to its shaft.

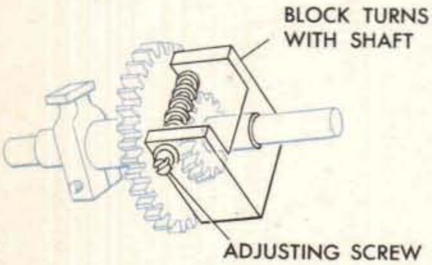
The vernier clamp consists of:



1 A sleeve with an ordinary clamp to hold the sleeve on the shaft.

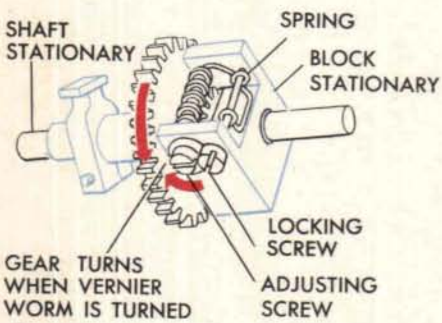


2 A gear that fits over the sleeve is free to turn on the sleeve. This gear has a special very small worm wheel on one end of its hub.



3 A block is pinned to the sleeve and holds a small worm. This worm meshes with the worm wheel on the gear hub. The adjusting screw in this block is turned to rotate the small worm and the gear.

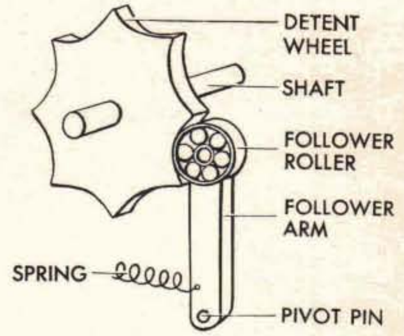
When the worm is turned, the worm wheel and the gear revolve together very slowly on the sleeve, altering the relative positions of the gear and the shaft.



When the gear and shaft have been correctly positioned, the adjusting screw is held in position by a locking screw, which clamps down on a flat portion of the adjusting screw, locking it in place.

The end shake in the worm is removed by a bent washer spring under a collar on the end of the worm. A wire spring acts to hold the worm closely meshed with the wheel to eliminate lost motion, so that any adjustment will be very accurate.

DETENTS

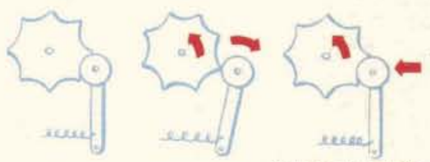


A detent is used to hold a shaft firmly in several definite positions. A detent will pull the shaft to one of the *exact* positions if it is released when *near* that position.

A feature of the detent is that it allows a quantity to be set at definite values quickly and accurately. However, no values can be set between those for which there are detent notches.

The detent consists of a specially shaped wheel fixed to the shaft and a follower roller on an arm.

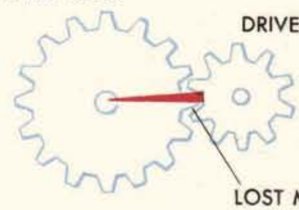
The roller is held between the teeth of the wheel by a spring on the follower arm.



When the shaft turns, the roller is forced out to the end of a tooth and the spring pulls the roller back between the next two teeth. The detent always holds the shaft between the teeth.

There are several other kinds of detents, designed for the special places where they work. They all do the same kind of job.

The TAKE-UP SPRING



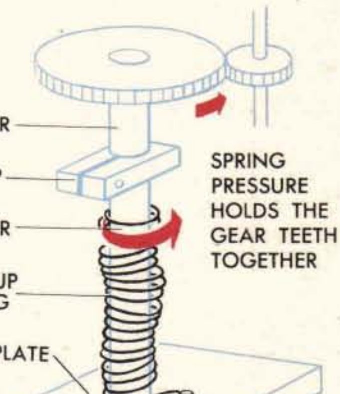
Take-up springs are used to remove lost motion between several pairs of meshing gears.

In each pair of meshing gears there is a small space between the meshing teeth when they are at rest.

When the driving gear begins to turn it must move through this space before it starts to move the driven gear.

The motion of the driving gear before it moves the driven gear is called *lost motion.*

Lost motion adds up to a considerable error on a long shaft line having many meshes.

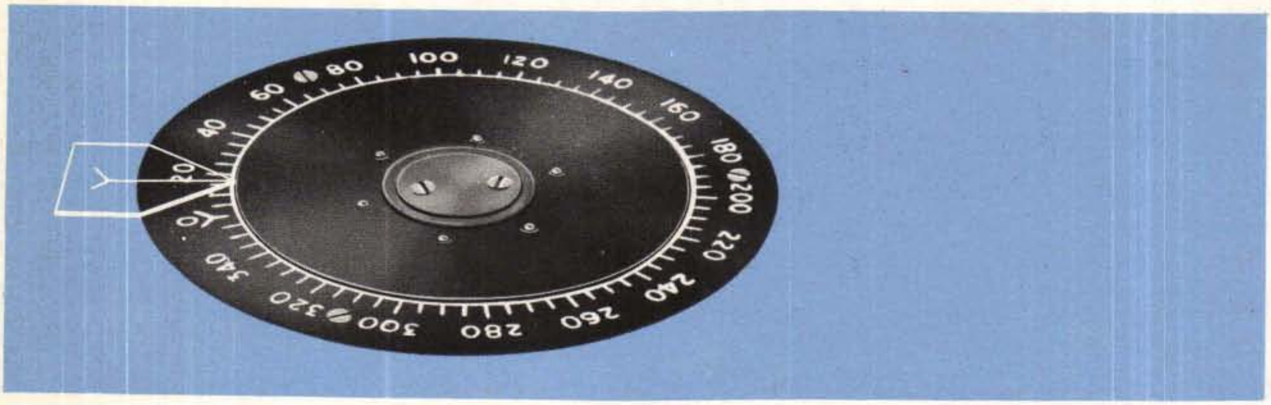


The take-up spring removes lost motion by holding the driving gear teeth firmly against one side of the driven gear teeth all the time, both while the shafts are turning and while they are stationary.

The take-up spring is attached at one end to a mounting plate and at the other end to a clamp on the shaft.

The clamp is held in place by spacers on the shaft. The spacers prevent the clamp from being pulled along the shaft when the spring is adjusted. The spring pressure can be adjusted by loosening the clamp screw and turning the clamp to wind the spring.

DIALS



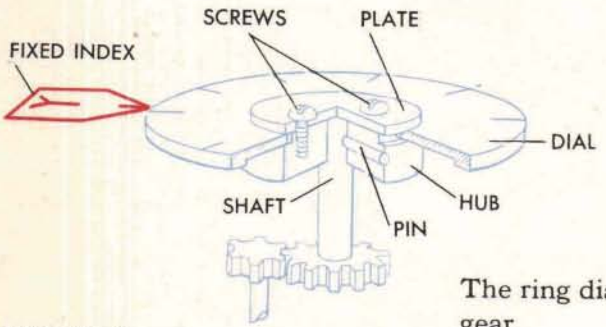
A dial shows the *position* of a line of shafts and the *value* on the line.

It is usually read against a fixed index.

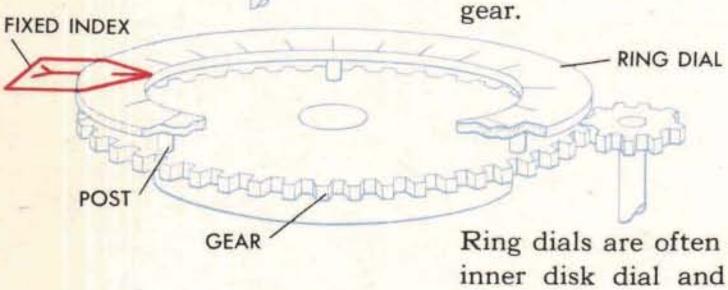
There are two kinds of dials, disk dials and ring dials.

The first consists of a disk which is held to a shaft between a hub on the shaft and a plate screwed to the hub.

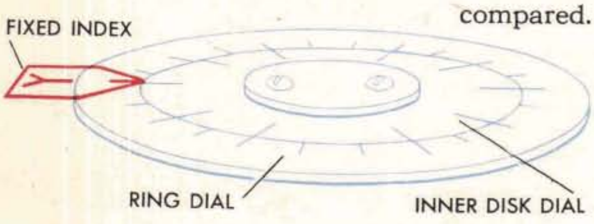
The position of the dial in relation to the shaft can be changed by loosening the screws and moving the dial around by hand.



The ring dial is mounted on posts on a gear, and driven by the gear.



Ring dials are often used together with disk dials, where the inner disk dial and the ring dial have to be matched or compared.



Fine and coarse dials

Where one dial only is needed to show the values on a line, a disk dial is generally used.

For more accurate settings a pair of dials are used so that one turns faster than the other and gives a finer reading of the value on the line.

The fine dial and the coarse dial work together like the minute and hour hands of a watch.

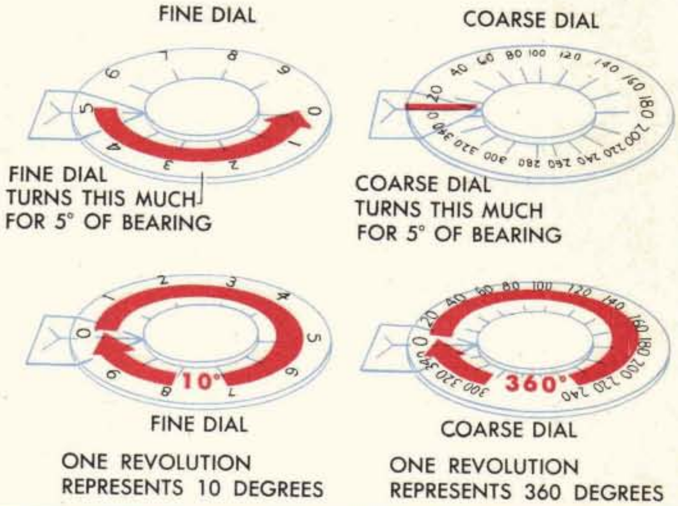
The fine dial turns a whole revolution while the coarse dial turns only part of a revolution.

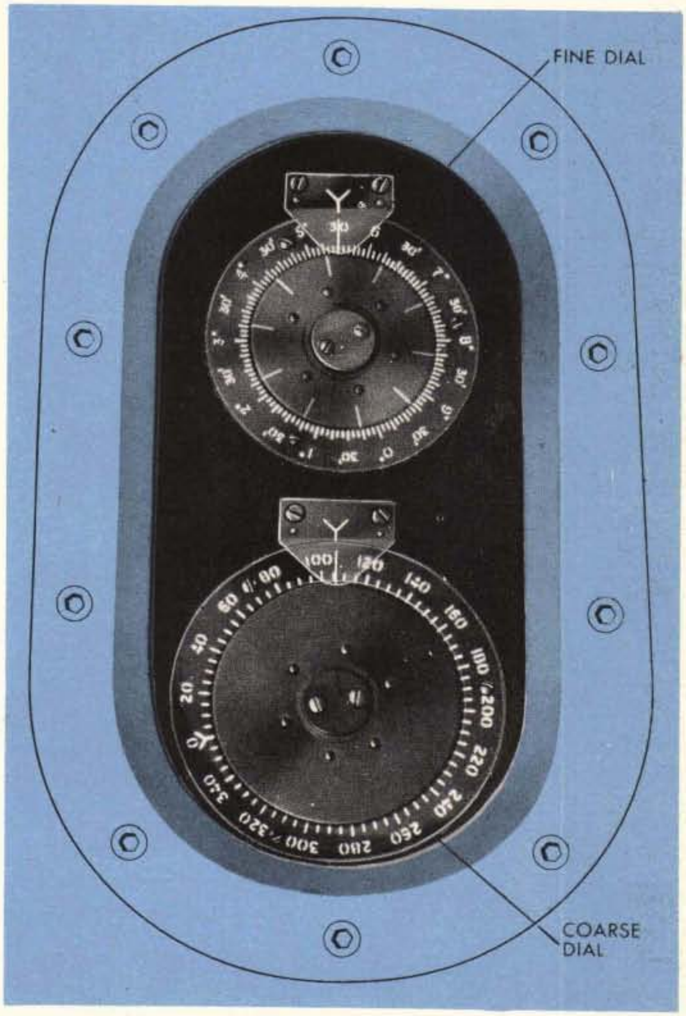
For instance, in the coarse and fine bearing dials of most computers, the coarse dial is graduated every 5°, and turns one whole revolution for 360°.

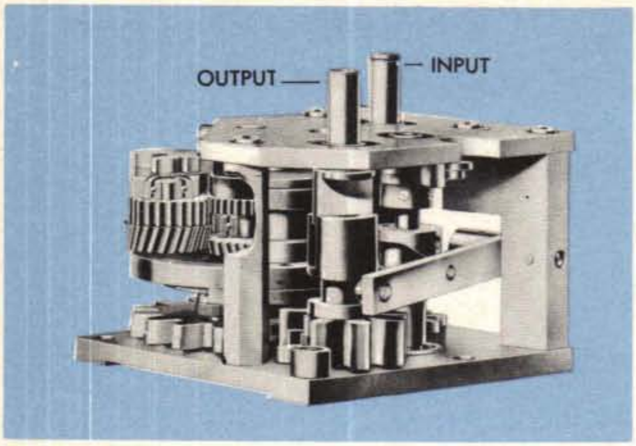
The fine dial is usually graduated every 5′ and turns one whole revolution for only 10° of bearing.

The coarse dial is driven by the fine dial through gearing. In the case of the bearing dials the fine makes 36 revolutions to one of the coarse.

To read these dials, read the coarse dial first. Take the lower 10° mark on the coarse dial and add to it the reading on the fine dial. The dials pictured at the right read 105° 30′.







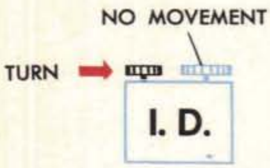
Setting the

The intermittent drive receives a quantity as an input and delivers as an output only that portion of the quantity which can be handled by the mechanism connected to it.

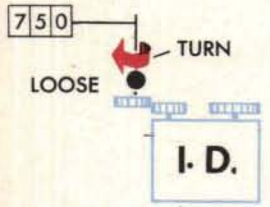
If an input value is within the limits of this mechanism, the intermittent drive allows the value to drive through, but if the value is *above* or *below* the limits, the intermittent drive delivers *no output.*

The purpose, when setting, is to have the intermittent drive set to its input counter so that it will "cut in" and "cut out" at the proper limits as shown on the input counter.

To set the input of the intermittent drive

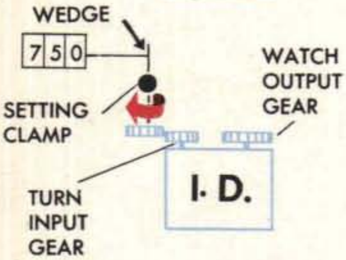


1 Turn the intermittent drive input gear in a decreasing direction until the output gear "cuts out," that is, until the output stops turning.



2 Set the input counter at the "cut in" reading for the lower limit. Wedge the input.

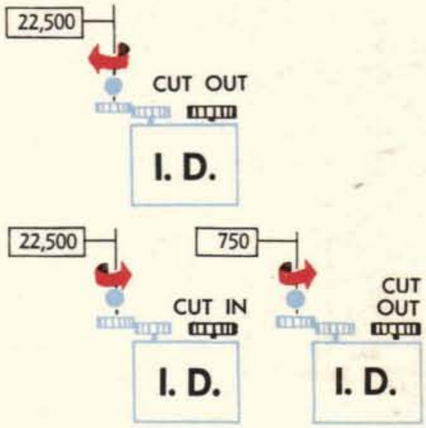
NOTE: The limits of the various intermittent drives will be given in each Computer's setting notes. In the examples used here, 750 is the lower limit, and 22,500 is the upper limit.



3 Turn the intermittent drive input gear in the increasing direction until the output gear just starts to move. The intermittent drive is now approximately set to the counter.

4 Slip-tighten the setting clamp.
Remove the wedge.

INTERMITTENT DRIVE



5 Keep turning the input shaft in the same direction until the intermittent drive "cuts out" at its upper limit.

Then start turning it in the *opposite* direction.

It will "cut in" again at the upper limit and "cut out" again at the lower limit.

The observed readings should agree with the true readings if the intermittent drive is set correctly.

6 Observe the input counter and fill the following table while doing step **5**:

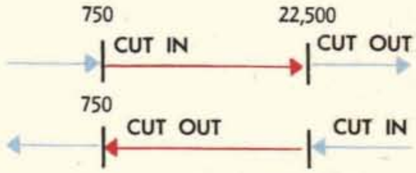
Intermittent drive "cuts in" at lower limit.

Intermittent drive "cuts out" at upper limit.

Intermittent drive "cuts in" at upper limit.

Intermittent drive "cuts out" at lower limit.

TRUE	OBSERVED
750	
22,500	
22,500	
750	



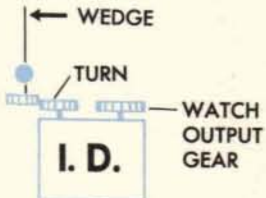
7 Here the intermittent drive is correctly set. The observed readings agree with the true readings. The intermittent drive must have "cut in" when the input counter indicated its "cut in" point.

TRUE	OBSERVED
750	750
22,500	22,500
22,500	22,500
750	750

8 Here the intermittent drive setting is incorrect. The observed readings disagree with the true readings because the intermittent drive "cut in" at the wrong reading.

750	745
22,500	22,495
22,500	22,495
750	745

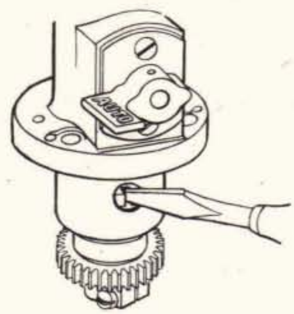
9 To correct the setting, position the input counter at the true reading for "cut in" at lower limit and slip the input gear shaft through the setting clamp until the output gear just begins to move.



10 Tighten the setting clamp.

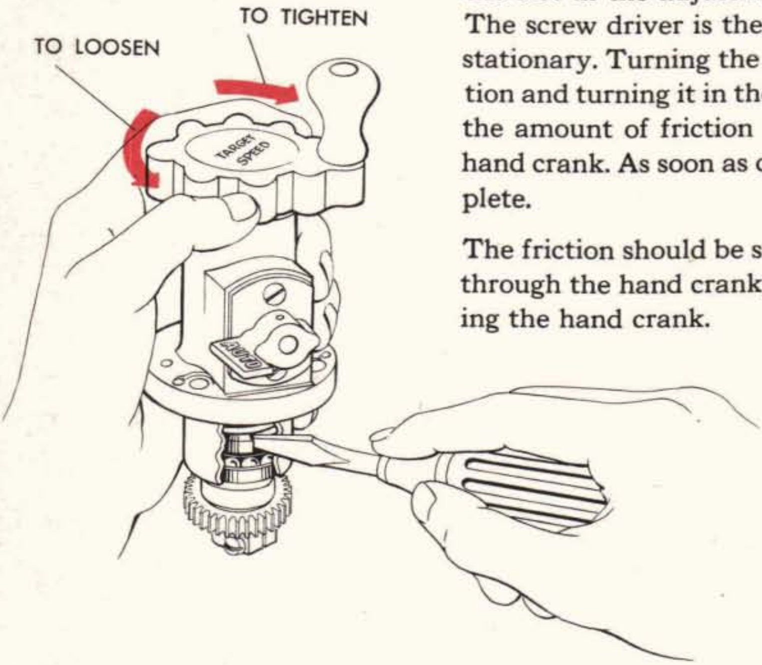
Recheck until the observed readings agree exactly with the true readings.

ADJUSTMENTS OF



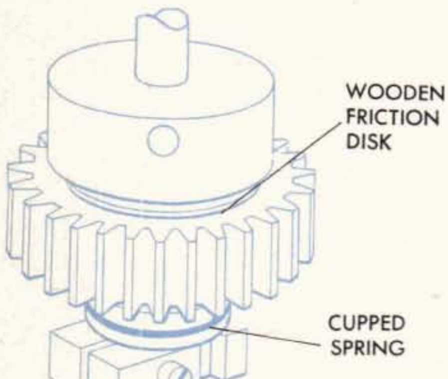
The adjustment of the frictions on hand cranks is very simple and the only tool needed is a screw driver.

The holding friction adjustment



The adapter has a small opening for a screw driver. The hand crank should be put in the OUT position, and then turned until the slot in the adjusting nut is in front of this small opening. The screw driver is then inserted into the slot to hold the nut stationary. Turning the hand crank clockwise tightens the friction and turning it in the opposite direction loosens it. To check the amount of friction remove the screw driver and turn the hand crank. As soon as drag is sufficient the adjustment is complete.

The friction should be sufficient to prevent motion backing out through the hand crank, but not great enough to prevent turning the hand crank.



The friction relief drive adjustment

In this type of friction a cupped spring and clamp are used to hold a maple wood friction disk against the gear on the shaft.

By loosening the screw in the clamp with a screw driver, the clamp can be screwed up on the shaft to increase the pressure of the cupped spring, or turned in the opposite direction to reduce pressure. Tightening the screw in the clamp will hold it in place, when the proper pressure is on the spring.

The friction is adjusted properly when the gear drives under a normal load, but slips when there is an overload.

HAND CRANKS

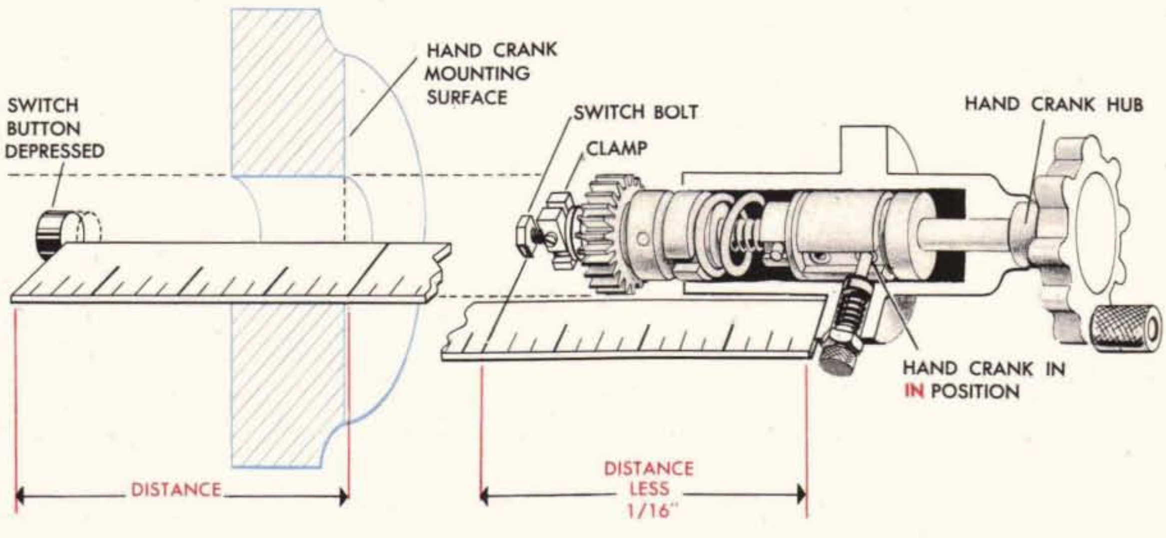
The switch bolt adjustment

On hand cranks having a switch bolt to depress a push button switch, adjustment of the position of the switch bolt is sometimes necessary. Loosening the screw in the clamp will free the switch bolt so that it may be screwed IN or OUT.

THE most accurate way to set the bolt is to remove the hand crank and measure the distance from the switch button when it is depressed to the hand crank mounting surface.

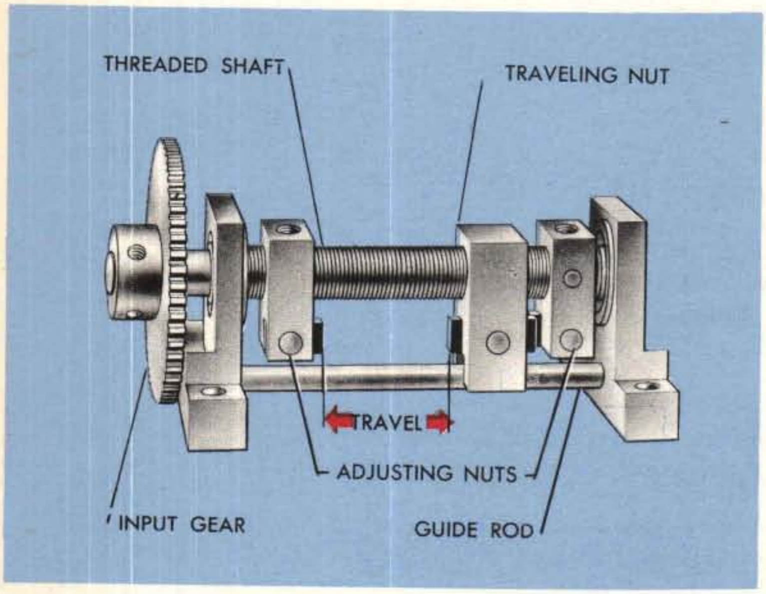
With the hand crank in its IN position, screw the switch bolt IN or OUT until the distance from the mounting surface of the flange to the bottom of the button is 1/16" less than the first measurement.

The switch bolt is in the proper position when it depresses the push button with the hand crank in its IN position but does not touch the push button when the hand crank is in its OUT position.

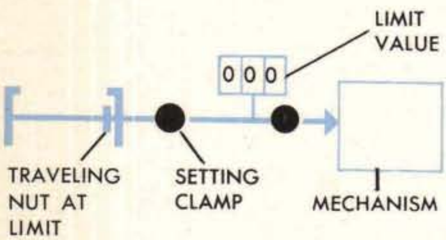


CAUTION:

After adjusting and remounting the hand crank, hold the plunger OUT and move the hand crank IN until the hand crank hub touches the adapter. If the hand crank cannot be moved IN to touch the adapter easily, the switch bolt is too far OUT and forcing the hand crank in may damage the switch.



Setting the LIMIT STOP



A limit stop is a protective device. It *limits the travel* of a shaft and so protects cams, lead screws, integrator carriages and other mechanisms.

The "travel" of a limit stop is determined by the number of turns its shaft can make while the traveling nut moves from one adjusting nut to the other. The travel of the limit stop is fixed when the limit stop is made.

To set the limit stop to the shaft which is to be limited:

1 Turn the limit stop to bring the traveling nut to one end of its travel.

2 Set the counter at the limit value for that point.

3 Tighten the setting clamp.

The counter and the limit stop are set together. Setting a mechanism to *either* the counter or the limit stop will now set the mechanism to *both*.

SECTION 3

ELECTROMECHANICAL UNITS

Most of the units in this section are divided into two groups:

a. Follow-up controls

b. Synchros

These two groups of units correspond to the two main types of jobs for which mechanical computers generally call upon the help of electricity:

a. One of these jobs is positioning mechanisms and lines of gearing quickly and accurately against loads which are too great for mechanism outputs alone to handle. Electric motors called "servos" are put into the computers and range keepers at points where additional torque is needed. These motors must be accurately controlled. To provide the necessary control a variety of devices has been developed called "follow-up controls."

b. The other main use for electricity in mechanical computers is to provide automatic reception and transmission of information. The electrical unit which is used for this purpose is called a "synchro." Sending information from one synchro to another is called "synchro transmission."

MAGNETISM and ELECTRICITY

The larger mechanical computers contain several different kinds of electromechanical mechanisms such as servo motors, synchros, and solenoid locks and clutches. It is necessary to know the basic principles of magnetism and electricity to understand how they work. This chapter is confined mainly to the facts about electricity and magnetism which will be of practical use in understanding and maintaining basic Ford electromechanical units.

Magnetism

In ancient times the Magnesites, a Greek tribe, noticed that certain pieces of iron ore attracted iron and other materials.

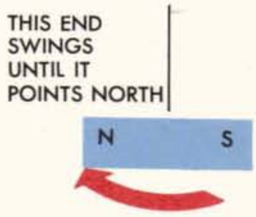
The iron pieces that had the power to attract became known as magnets in honor of the people who had discovered them.

Later it was learned that it was possible to make artificial magnets from other pieces of iron or steel by stroking them with a natural magnet several times in the same direction. Then it was no longer necessary to search for natural magnets. Man could make his own.

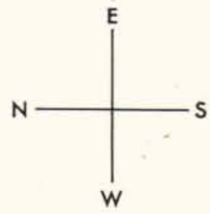
Modern artificial magnets have many uses in fire control systems.

Magnetic poles

A bar magnet is a bar of steel that has been magnetized. If a bar magnet is placed in a dish of iron filings, some of the filings will cling to the bar when it is taken out of the dish. Most of the filings will cling to the ends of the bar with only a few around the center portion.

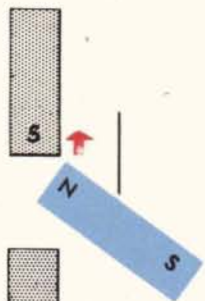


Magnetic strength is greater near the ends of the bar. The ends of the bar are called the *poles* of the magnet. Every magnet has two poles. One is known as the North pole, and is usually shown as *N* on a diagram. The other pole is known as the South pole, and is marked *S*.



If a magnet is suspended horizontally so that it is free to move, it turns slowly until one end points north. No matter how often the magnet may be swung away from this position, this same end of the magnet always returns and points north. This north-seeking end of the magnet is its *north pole*. The opposite end is the *south pole*. A magnet behaves this way because the earth itself is a magnet. A magnet suspended like this is a compass.

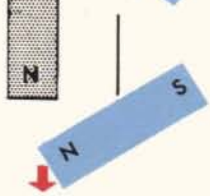
Attraction and repulsion between poles



If the *S* pole of a second magnet is brought near the *N* pole of the suspended one, the *N* pole of the suspended magnet turns *toward* the *S* pole of the second magnet.

There is a strong force trying to pull the magnets together. In fact, the *N* pole of the suspended magnet would come together with the *S* pole of the other one if allowed to.

UNLIKE MAGNETIC POLES *ATTRACT* EACH OTHER.



Now if the *N* pole of a second magnet is brought near the *N* pole of the suspended one, the *N* pole of the suspended magnet turns *away* from the *N* pole of the second magnet.

There is a strong force repelling the two like poles.

LIKE MAGNETIC POLES *REPEL* EACH OTHER.

Why magnetism works

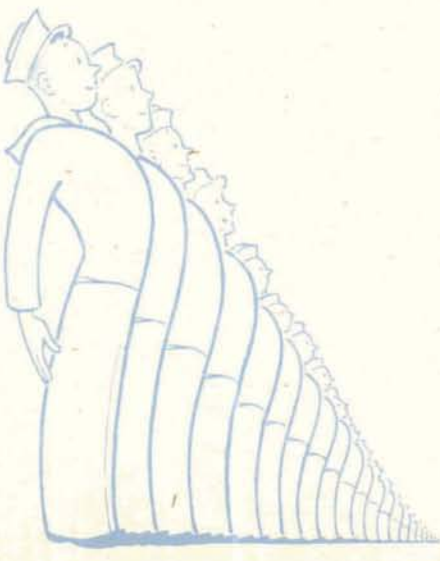
Why should a piece of steel or iron become a magnet, and be able to give evidence of such things as magnetic poles?

Certainly no outward change occurs. The piece of steel remains a piece of steel. The piece of iron remains a piece of iron.

Yet something happens, and it can be explained this way:

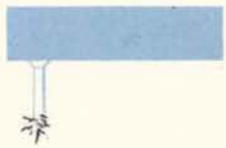
Each of the molecules (or very small particles) that make up the steel or iron is a tiny permanent magnet. Normally, these tiny magnets are arranged helter-skelter like the members of a crew waiting around for the signal to "fall in." When the bar is magnetized, the molecules line up in order and all face the same way like a crew at attention. The molecules lined up in proper formation are able to do jobs they were not able to do previously.

The tiny magnets line up so that their N poles all point toward one end of the bar. The S poles all point in the opposite direction. The N and S poles of the tiny magnets tend to neutralize each other in the middle of the bar. But at one end there is a set of unneutralized North poles and at the other, a set of unneutralized South poles. This explains the magnetic strength at the ends of the bar while the middle is comparatively weak.

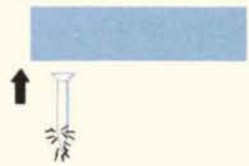


Magnetic induction

A piece of iron or steel can be magnetized by stroking it with another magnet. But it can also become magnetized temporarily *without* being actually touched by a magnet.



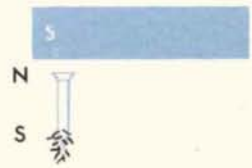
When a permanent magnet is placed *against* one end of a nail and the other end of the nail is brought into contact with iron filings, a mass of filings will cling to the nail. The nail itself has become a magnet.



When the nail is moved a little distance away from the permanent magnet, the filings still cling to it. The nail is still a magnet without being in contact with the permanent one. The nail acts as an extension of the magnet without touching it.

MAGNETISM PRODUCED *WITHOUT CONTACT* IS *IN DUCED* MAGNETISM.

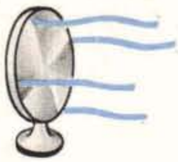
If the nail is moved farther away from the permanent magnet, the filings drop off. This shows that the nail was only a temporary magnet.



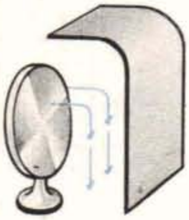
While the nail remains a magnet, it must have poles. To find the positions of the poles, the nail is brought up to the permanent magnet. The nail is attracted, and becomes attached to the magnet.

According to the rules of attraction and repulsion, unlike poles attract each other. If the pole of the permanent magnet that is near the nail is S, the induced pole attracted to the magnet is N. If the pole of the permanent magnet happens to be N, the induced pole attracted to it will be S.

Lines of Force



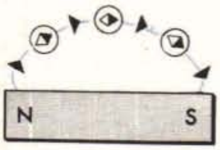
The lines of force around a magnet are invisible. But there are a lot of invisible things that can be proved to exist. For instance air and its flow are both invisible. But if an electric fan is turned on and strips of cloth are attached to the front frame, the waving of the strips show the flow of air that is created by the fan.



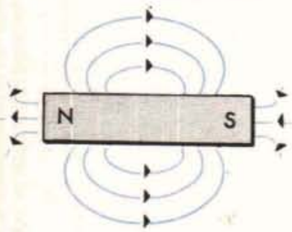
If the flow of air is deflected by a shield its direction could be represented by arrows.

In much the same way the invisible lines of force around a magnet can be shown.

In place of the cloth strips to show the flow of air from the fan, a compass is used to find the lines of force around a magnet.

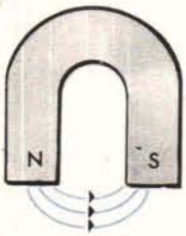


The compass is first placed near the *N* pole of the magnet and moved in the direction toward which the *N* end of the compass needle points. The compass marks out a path in a wide curve to the *S* pole of the magnet. This curve is the path of a line of force.

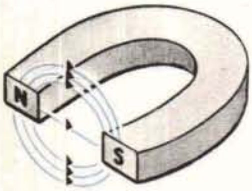


If this operation is carried out several times, the paths of the lines of force look like this, with the arrows showing the direction of travel.

Magnets of different shapes



Magnets are not all in the shape of a bar. The bar can be bent into a horseshoe shape. This is one of the most common shapes of a magnet.

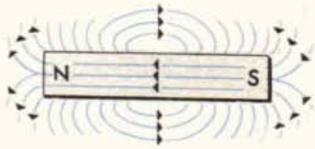


The lines of force around the poles of a horseshoe magnet seen from the bottom take this pattern.

The Magnetic Field

The many lines of force around a magnet form the *magnetic field.*

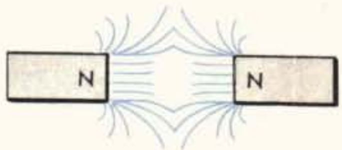
This field can be seen by covering the magnet with a piece of paper, sprinkling iron filings on the paper, and tapping it gently.



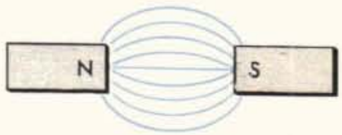
Each filing becomes a temporary magnet and sets itself in the direction of the line of force.

The filings lining up on the many lines of force show the pattern of the particular slice of the magnetic field through which the paper cuts.

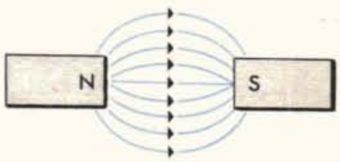
The pattern shows how the lines of force leave the magnet at the *N* pole, curve around and enter the *S* pole. In the magnet itself the lines pass straight from the *S* pole to the *N* pole.



If the *N* poles of two magnets are brought near each other, the lines of force repel each other. This is to be expected since *like* poles *repel* each other.



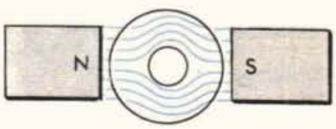
If the *N* and *S* poles of two magnets are brought near each other the lines of force pass from the *N* pole of the one magnet to the *S* pole of the other one. This shows again that *unlike* poles *attract* each other. The compass needle showed that magnetic lines of force travel from a *N* pole to a *S* pole.



Good and bad conductors

It is easier for magnetic lines of force to travel through some materials than through others.

A material that allows an easy passage of the magnetic lines of force is known as a *good magnetic conductor*. When such a material is brought near a magnet, as many lines of force as possible try to crowd their way through.

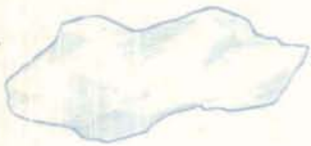


If an iron ring is placed between two unlike poles, the lines of force crowd through the iron of the ring instead of going around it. Very few of the lines travel across the hole in the ring, even though the distance through the hole is the shortest.

This shows that the lines of force find it easier to travel through iron than air.

The ease with which lines of force travel through a material shows the *permeability* of the material. The permeability of iron is great. The permeability of brass, glass, air, and other nonmagnetic materials is small.

Electric current is a flow

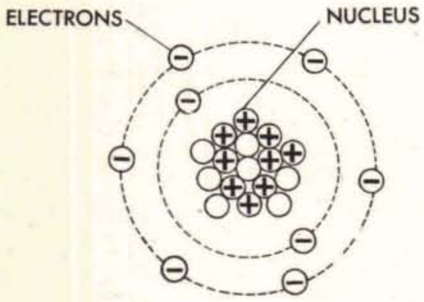


ALL MATERIAL THINGS ARE MADE OF ATOMS

Electricity is a flow, but an invisible one. It is a flow of electrons.

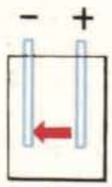
An electron is a part of an atom.

All material things are made of atoms. The smallest thing visible under an ordinary microscope is made of almost countless numbers of atoms.

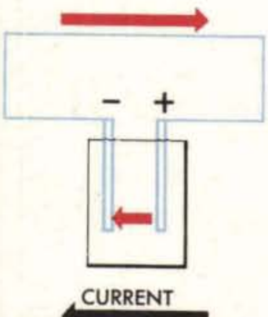


TYPICAL ATOM

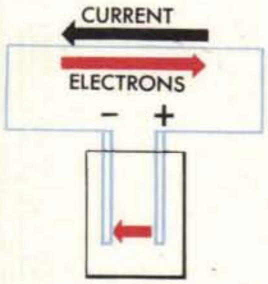
Each atom consists of electrons moving around a center. Each electron holds a negative charge of electricity. The center of the atom holds a positive charge. As in magnetism, unlikes attract, so electrons can be attracted by a stronger positive charge in another atom. This starts a flow of electrons from one atom to another.



In an electrical battery different metals are used for the poles. Chemical action is set up by the material in which the metal is placed. Then, the electrons collect on the negative pole.



If the poles are connected by a wire, the electrons that have collected on the negative pole flow *through the wire from the negative to the positive pole*. As chemical action is still taking place inside the battery, the electrons *in the battery cell* flow from the *positive to the negative pole*. In this way a complete circuit circle is made when an electric current is set up.



For many years it has been customary to consider the electric current as flowing from positive to negative. It is too late now to try to change this custom, so it is necessary to remember that the *current flow* is represented in diagrams as being *opposite* to the direction of the actual *electron flow*.

So much for pure theory—now for some definitions . . .

Measuring electricity

Energy

Electricity is a form of energy. Energy is the ability to perform work. Man has energy because he can lift things and carry burdens. Coal has energy because it can do work by producing heat. The powder charge in a gun has energy because it can do work by producing rapidly expanding gases upon explosion.

In performing work, electrical energy invariably takes other forms. When electricity is used to lift a load, electrical energy is transformed into *mechanical* energy. When electricity is used to heat furnaces, electrical energy is transformed into *heat* energy. When electricity is used to produce light, electrical energy is transformed into *light* energy.

Work

The most useful characteristic of electricity is its ability to perform *work*. Work may be defined as the overcoming of resistance. If a load of 50 lb. is lifted 1 ft., 50 ft. lbs. of work have been performed. Work is *measured* by multiplying the load displaced by the distance it is moved.

Power

Power is the rate at which work is done. A small electric motor with proper gearing might lift a given load 10 ft. in an hour. A larger motor that lifted the same load in 10 minutes would be six times as *powerful*.

Volts

The *pressure difference* that produces a flow of electricity is measured in *volts*. Comparing electricity with water, the voltage of electricity can be compared to the pounds of *pressure* per square foot exerted by a mass of water against the walls of a container.

Amperes

The rate of *flow* of electricity is measured in *amperes*. Just as the rate of flow of water is measured in so many gallons a minute, the rate of flow of electricity is measured in so many amperes.

Ohms

The *resistance* of any material to the passage of an electrical current is measured in *ohms*. Some materials are better conductors of electricity than others. Every material, however, offers *some* opposition to the flow of electricity. This opposition is known as *electrical resistance*.

Watts

The power of electricity is measured in *watts*. Power depends upon the rate of flow and the pressure. A watt, then, equals *one ampere* multiplied by *one volt*

OHM'S LAW for direct current

NOTE:

When applying Ohm's Law to alternating current, resistance of the material is not the only resistance encountered. All electrical circuits resist any change in the flow of current. Because alternating current changes direction 120 times a second, this resistance called inductive resistance must be taken into consideration. When measuring alternating current, the inductive resistance is added to the resistance of the material and the two together are called the impedance.

Ohm's Law for alternating current is written

$$\text{Current} = \frac{\text{Voltage}}{\text{Impedance}}$$

When two measurements of an electrical circuit are known, it is easy to find the third measurement by Ohm's law. This law was named after George Simon Ohm who discovered it.

The law itself is expressed in this formula: $I = \frac{E}{R}$

I is the symbol for the current in amperes.

E is the electromotive force or difference in pressure between two points, expressed in volts.

R is the resistance of the circuit in ohms.

If there is a pressure difference of 6 volts and the circuit has a resistance of 3 ohms, $E = 6$, and $R = 3$. Then $I = 6/3$, or $I = 2$ amperes.

This law can be expressed in different ways. To find the resistance of a circuit, the formula can be turned around to read

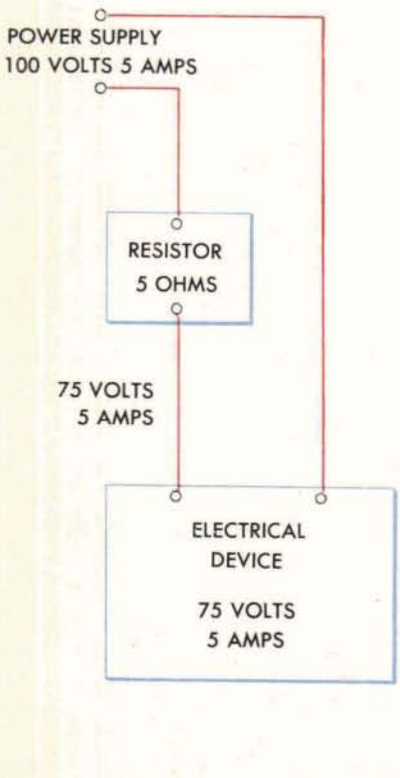
$$R = \frac{E}{I}$$

Using the same figures, with a pressure of 6 volts, and a flow of 2 amperes, $R = 6/2$, or $R = 3$ ohms.

To find the voltage drop when the current and the resistance are known, the formula is $E = IR$

Using the same figures again, where $I = 2$ and $R = 3$, $I \times R$ or $2 \times 3 = 6$ volts. So $E = 6$ volts.

By definition: Watts = amperes $\times$ volts $W = IE$
but since $E = IR$ W also $= I \times IR$ or $W = I^2R$



Controlling the current

Every electrical device is designed to operate within a certain voltage range. In order to use such a device in a circuit having a voltage higher than that for which the device was designed, it is necessary to reduce the voltage. A voltage dropping resistor can be used for this job.

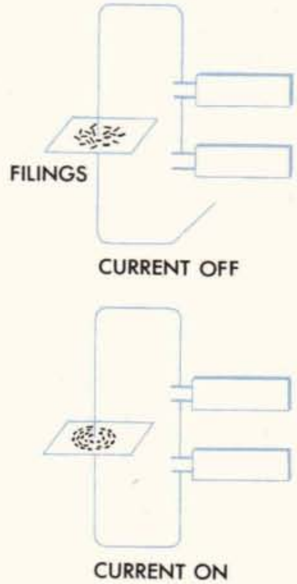
For example, an electrical device designed to operate at 75 volts with a current of 5 amperes, is to be operated on a 100 volt power supply. In this case the voltage applied to the device must be dropped 25 volts, and the current must be maintained at 5 amperes. Since voltage drop, E, equals current, I, times resistance, R, then $R = \frac{E}{I}$

Substituting the actual values in the equation,

$$R = \frac{\text{25 volts}}{\text{5 amperes}} \quad \begin{matrix}\text{(desired drop in voltage)} \\ \text{(desired current flow)}\end{matrix} \qquad R = 5 \text{ ohms}$$

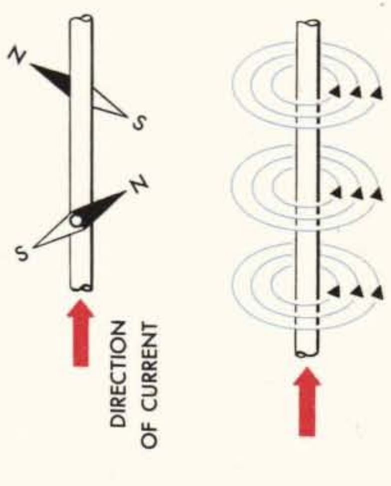
Thus a 5 ohm resistor connected in the circuit will drop the voltage to 75, which is within the operating range of the device to be protected.

The directions of lines of force in a magnetic field



An electric current sets up a magnetic field.

The presence of this magnetic field is easy to prove. A wire is run vertically through a hole in the center of a horizontal cardboard sheet on which iron filings have been sprinkled. When the ends of this wire are connected to a battery, current will flow through the wire. If the cardboard sheet is now tapped gently, the iron filings will form concentric circles around the wire. These circles show the path of the lines of force in a magnetic field set up by the current flowing through the wire.



The *direction* of the lines of force in the magnetic field around the wire can be found by means of a compass.

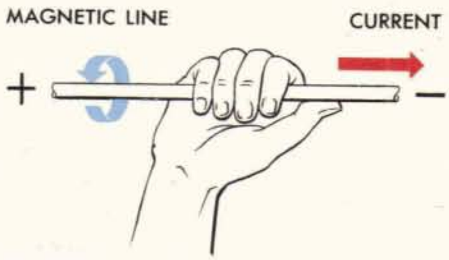
If a wire with current running through it is placed on top of a compass, the north-seeking end of the needle turns at right angles to the direction of the current.

If the compass is put on top of the wire, the north-seeking end of the needle points in the opposite direction.

The north-seeking end of the compass needle indicates the direction of the lines of force in the magnetic field around the current flowing through the wire.

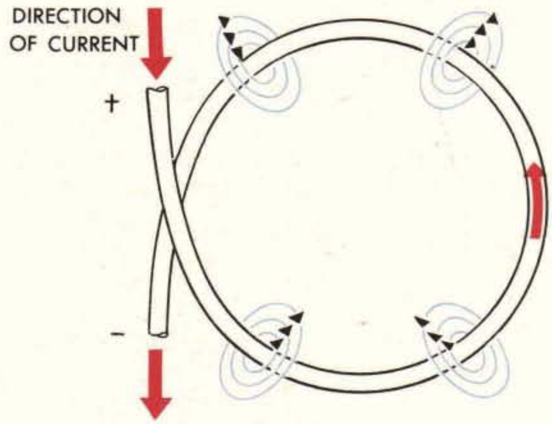
By placing the compass at various points around the wire, it is found that the lines of force make circles around the wire.

There is an easy method to find out the direction of lines of force in the magnetic field around a wire when the direction of the current is known. With the right thumb pointing along the wire in a direction from plus to minus, the fingers point in the direction of the field when the hand grasps the wire.

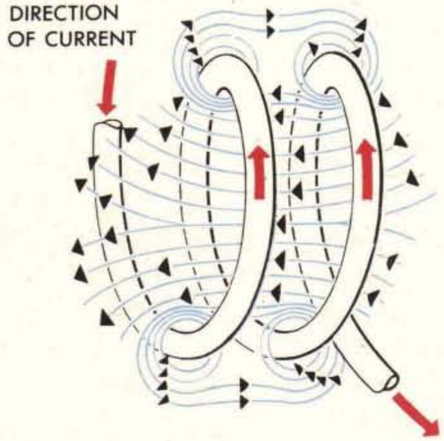


How a coil of wire produces

If a wire is made into a loop and a current of electricity runs through it, the rule of thumb still holds true. Grasping the wire with the right thumb pointing in the direction in which the current is flowing, the fingers point in the direction of the magnetic field.

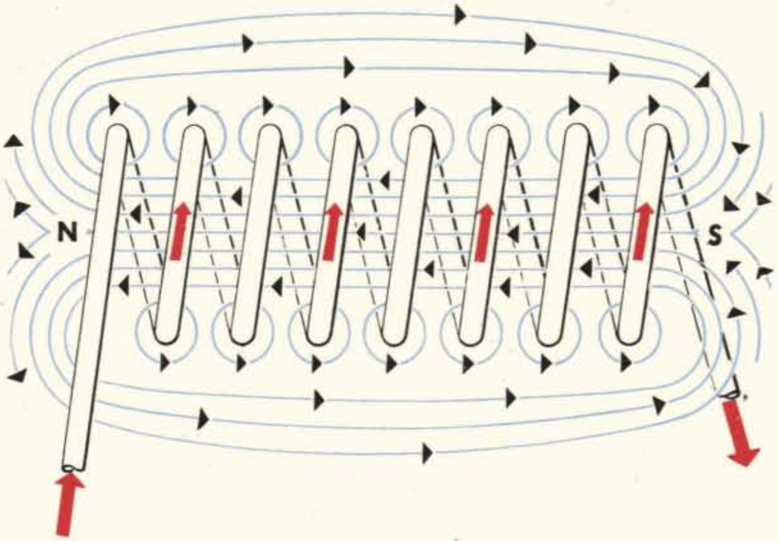


When the wire is coiled into two loops, most of the lines of force become big enough to include both loops. Their paths go through the loops in the same direction, circle around the outside of the two coils and come in at the opposite end.



a magnetic field

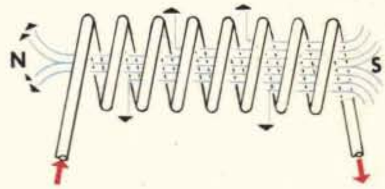
When the wire is looped a number of times, the lines of force make a pattern through all the loops. If the coil is grabbed by the right hand, with the fingers pointed in the direction of the current flow, the thumb points to the N pole of the coil's field.



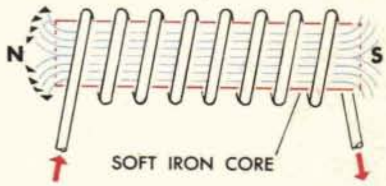
It's easy to see that this looks just like the magnetic field around a bar magnet. In fact, the coil has become a magnet.

A coil like this with air space through it is known as a *solenoid*.

Many of the lines of force, however, tend to stray between the loops of the solenoid, as indicated here. The magnetic force is thus scattered, or dissipated. To prevent such dissipation, a bar of soft iron is placed inside the coils of the solenoid.



The iron core affords an excellent path for the lines of force, which now become largely concentrated in the bar. This combination of coils and iron core produces an electromagnet.

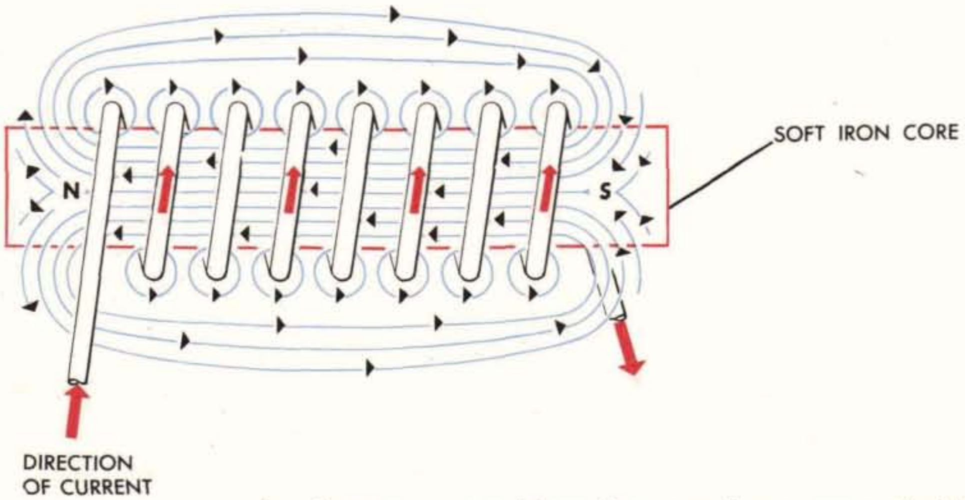


Strengthening the magnetic field

The strength of the magnetic field around an electromagnet can be increased either by increasing the number of loops in the wire or the flow of current through the wire.

Doubling the number of loops approximately doubles the strength of the field, each new loop adding its magnetic field to that already established. Doubling the amperage approximately doubles the strength of the field. Doubling the number of loops *and* doubling the amperage makes the field approximately four times as strong.

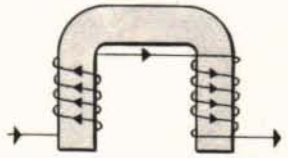
At a certain point, depending upon the size of the core of the electromagnet, a saturation point will be reached. Beyond this point, increasing the number of turns or increasing the amperage will not increase the strength of the field.



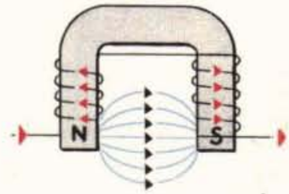
An electromagnet with an iron core has a magnetic field only while current is running through its coils. A reversal of the current reverses the poles.

An electromagnet need not be straight

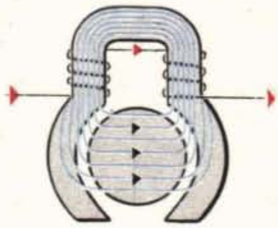
The soft iron core of an electromagnet can be bent into the shape of a horseshoe. A great many turns of wire are used in actual practice. For the sake of showing the direction of the current, only a few turns of wire are shown in the illustration.



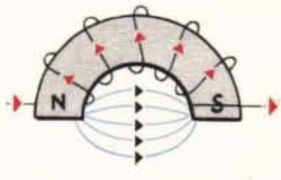
Following the laws of magnetism the magnetic field has its greatest strength at the poles. The field looks like this.



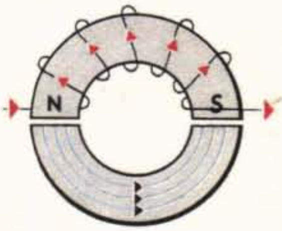
The arms of the iron core are often bulged. An iron disk or ring is put between them. Then the lines of force go through the disk or ring with very little leakage into the air between the poles.



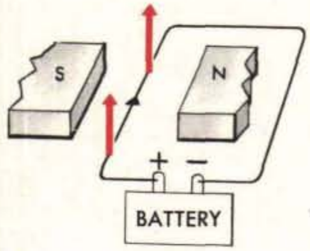
The electromagnet can also be bent into a semi-circle. The magnetic field has the same shape as in the horseshoe.



Then if another semi-circle of iron is fitted onto the magnet, practically all the lines of force go through the second semi-circle. Almost none of the lines of force escape into the air. This is one of the strongest kinds of electromagnets.

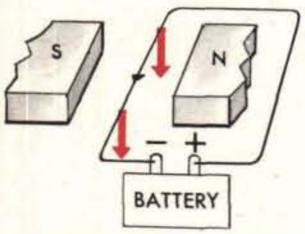


How magnetism makes

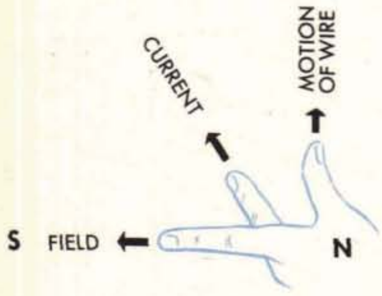


Place a length of wire between the poles of either a natural or an electromagnet. Attach the ends to the terminals of a battery with a switch in the line.

As soon as the current is turned on, the wire is kicked upward as shown by the red arrow.

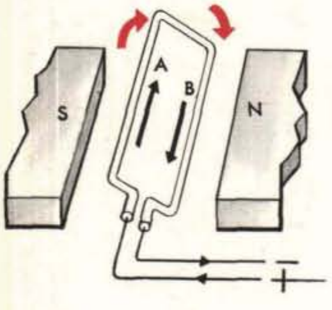


Reverse the connections to the battery. The wire between the magnetic poles is kicked downward.



Here is a rule for finding out the direction of the current as well as the direction in which the wire will be kicked:

Place the thumb and first two fingers of the *left* hand in the position shown. The first finger must be pointed from the *N* pole of the magnet to the *S* pole. Then the second finger shows the direction in which the current is flowing. The thumb points in the direction that the wire will move.

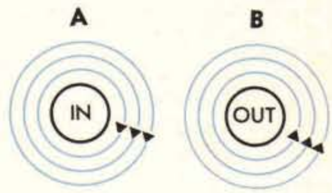


The direction of a current in one side of a loop of wire is opposite to the direction on the other side. When the loop is placed in a magnetic field, one side *A* kicks upward. The other side *B* kicks downward. If one side goes up and the other side goes down, the loop turns around, or rotates.

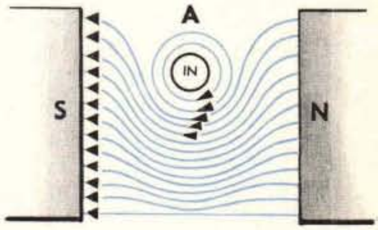
a motor turn

Here's why one side of the loop goes up and the other side goes down.

A magnetic field is produced around a wire when an electric current flows through it. Looking at the "IN" and "OUT" ends of the wire that forms the loop, the magnetic lines of force look like this.

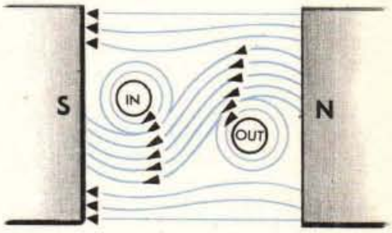


When the loop is put between the poles of a magnet, the magnetic field around the wire combines with the field between the poles of the magnet. Looking at the end of the wire where the current is flowing in, it is seen that more lines of force gather under the wire than above it.



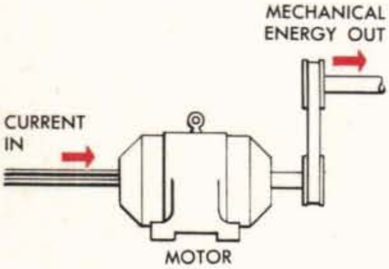
It is the natural tendency of the lines of force to take the shortest path between the poles of the magnet. It can be compared with the tendency of a rubber band to straighten out when stretched. Anything on top of the rubber band will be pushed up. In the same way the wire is pushed up by the lines of force because there are more lines of force under the wire than over it. This is called the *motor effect*.

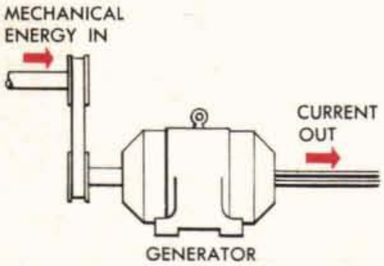
When the lines of force around the "OUT" side of the loop combine with the magnetic field between the poles of the magnet, there is a concentration of the field above the wire. This tends to push the "OUT" side of the wire down.



So the loop rotates as one side is pushed up and the opposite side is pushed down. A shaft attached to the loop would turn with it, and could be used to perform many jobs. Then the whole assembly is the basis of a motor.

Contrast between electric motors and generators

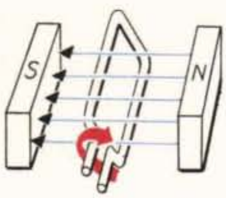




It has been shown that when a wire loop is placed in a magnetic field and an electric current is passed through the loop, the loop rotates. Rotation of such a loop can be used to supply mechanical energy. For instance, in an electric motor, many loops or "coils" are wound around the rotor of the motor, and the rotor is placed in the magnetic field produced by poles of an electromagnet. When current is supplied to these coils the rotor turns. A pulley or gear is attached to the rotor and, by means of belting or gearing, other mechanisms are driven. An input of electrical energy to the motor, therefore, results in an output of mechanical energy which can be used to drive various types of mechanical apparatus.

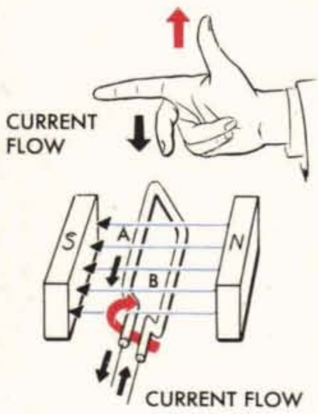
The opposite operation can also be performed. The coils of a rotor can be turned by mechanical means, and current can be obtained from the coils. In this case, an input of mechanical energy results in an output of electrical energy. The machine which converts mechanical to electrical energy is a *generator.*

It can be said that in a *motor,* electricity produces magnetism, and in a *generator,* magnetism produces electricity.



How magnetism generates electricity

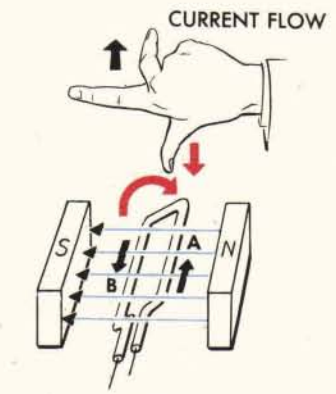
It is easy to construct a simple generator by putting a loop of wire between the poles of a magnet. As the loop is turned, it cuts the lines of force between the poles. This induces an electric current in the loop. Then current flows through the wire in a direction that can be determined by this *right* hand rule:



The first finger points from the *N* to the *S* pole of the magnet. The thumb, at right angles to the first finger, points in the direction of the motion of the rising wire *A.* Then the second finger, held at right angles to the wrist, points in the direction of the current in this wire.

Alternating Current

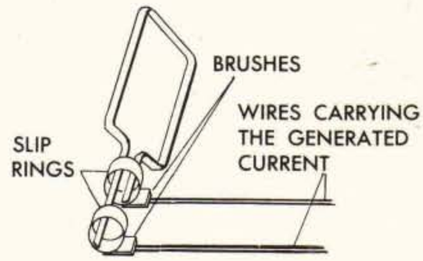
Alternating current is a flow of electricity that alternates from one direction to the other. It can be generated in a magnet and wire loop set-up like this:



It has been seen that as wire *A* moves upward through the magnetic field, cutting the lines of force, the right-hand rule shows the direction of current flow.

As the loop continues to rotate, wire *A* reaches a maximum point in its upward travel and then starts moving in a downward direction. Since wire *A* is now cutting the lines of force by traveling in the opposite direction, it is necessary to turn the right hand upside down to find the direction of current flow. It will be seen that when the direction of travel of wire *A* reverses, the direction of the current reverses. This occurs with each complete half turn of the loop.

The loop of wire turning constantly in the magnetic field now generates *alternating current*. Alternating current is usually abbreviated A.C.

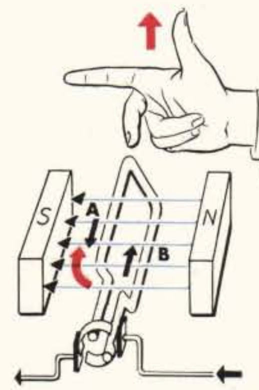


With this set-up, it would not be possible to turn the loop many times without the lead wires which receive current from the loop becoming entangled. The ends of the loop, therefore, are attached to slip rings which turn with the loop. Pieces of spring metal, known as brushes, press against the rings and carry the current flow to the wires.

Direct Current

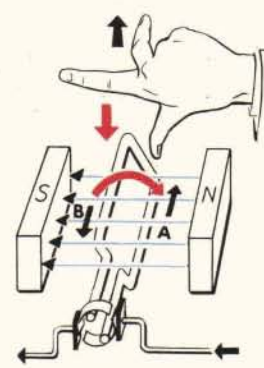
Direct current is a flow of electricity that remains constantly in one direction.

To make a generator supply direct current, a split ring is put on the axle that turns the loop. This split ring is known as a commutator.



When wire *A* is moving up, the current as shown by the right-hand rule, is coming off the loop through one half of the commutator and the upper brush.

When *A* has passed its maximum point of upward travel and is descending, the current in the loop is reversed. But the *A* part of the loop is now connected with the lower brush. The current, therefore, goes out in the same direction as before.



The upper brush is always connected to the part of the loop that is going up.

The lower brush is always connected to the part of the loop that is going down.

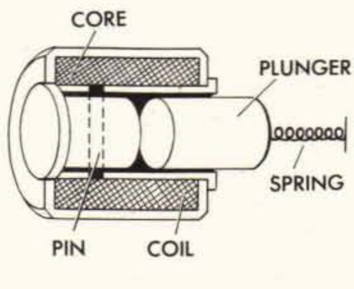
This being so, the direction of the current remains the same all the time in the outside lines.

SIGNAL, LOCK and CLUTCH

SOLENOID SIGNALS

Signals are a convenient device for saying YES or NO. An example of their use is in the Computer Mark 1, where they are turned on to say "YES, rate control corrections are being made at the director," or left off to say "No corrections are being made."

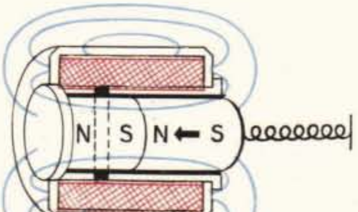
Reviewing Solenoid Action



A simple solenoid is a coil of wire.

The solenoid used in the solenoid signal contains a steel core and a steel plunger.

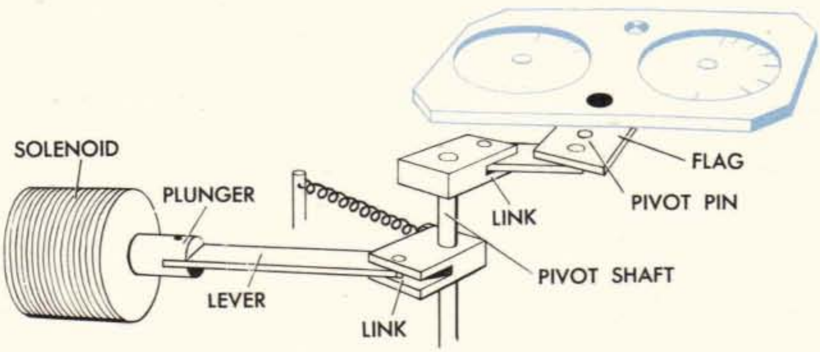
When the current is off, the plunger is held away from the core by a spring.



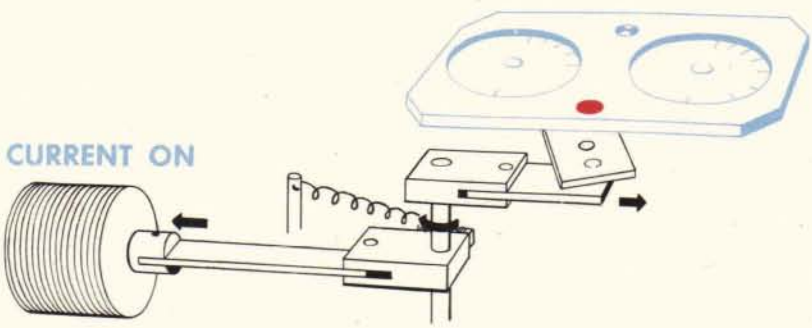
When the coil is energized, a magnetic field is formed inside it. The core and plunger become magnets, and their opposite poles are attracted to each other. Since the core is pinned in position, the magnetic attraction draws the plunger into the coil.

How the signal works

In the solenoid signal, the plunger is connected through levers and links to the signal flag.



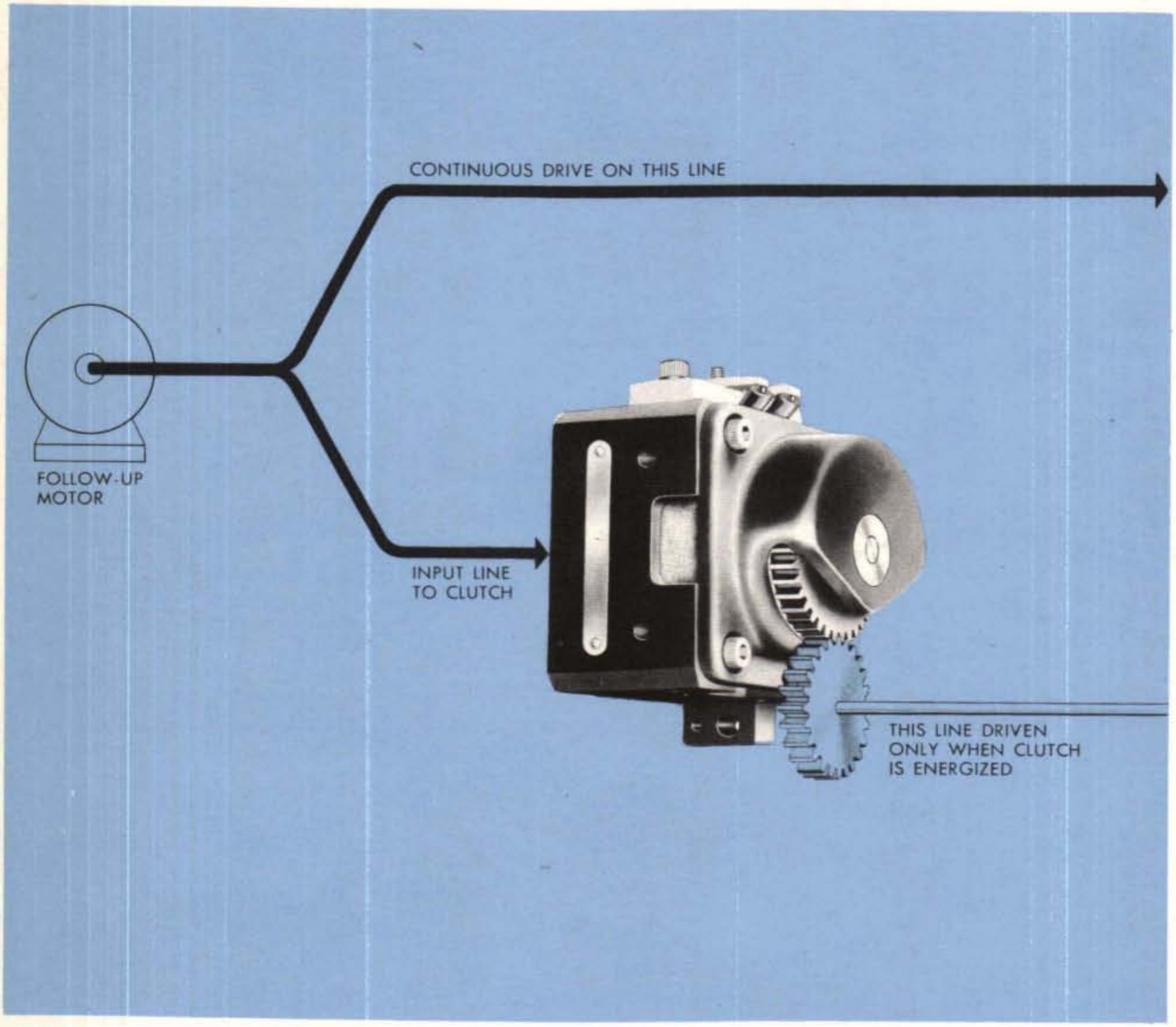
When the solenoid is not energized, the spring holds the black part of the signal flag under the hole in the dial mask.



When the rate control key in the director is pressed the solenoid is energized.

The plunger is pulled into the solenoid coil. This turns the pivot shaft and swings the red part of the signal flag into view under the hole in the dial mask.

The Solenoid CLUTCH



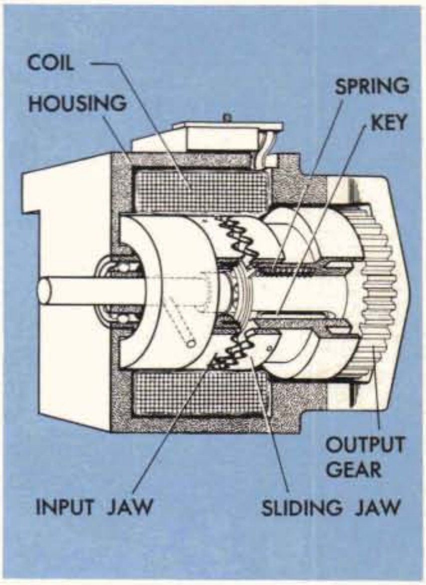
THIS IS HOW THE CLUTCH IS SHOWN ON SCHEMATICS

A CLUTCH connects and disconnects a line of gearing.

When this clutch is engaged the motor drives the output line from the clutch. When the clutch is open, the output line from the clutch will not be turned even though the motor continues to drive the input.

The clutch jaws are held open by a spring until they are engaged by the same kind of solenoid action which operates the solenoid signal just described.

An inside view of the clutch



The solenoid clutch consists of two cylindrical jaws set inside a solenoid coil.

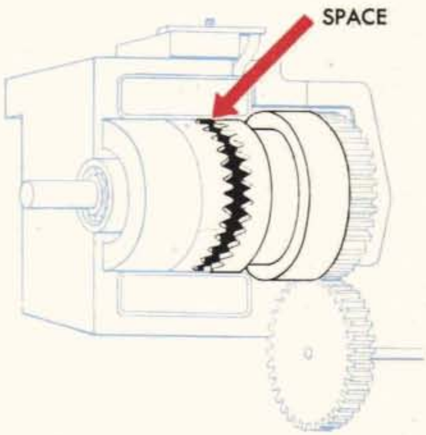
The *input* shaft rotates one jaw.

The other jaw is mounted on the hub of the *output* gear. This is the *sliding jaw.*

The sliding jaw is free to slide on keys which are set between the jaw and the hub of the gear. While the keys allow the jaw to slide back and forth on the output gear hub, they prevent the jaw from turning on the hub. The hub and jaw must turn together.

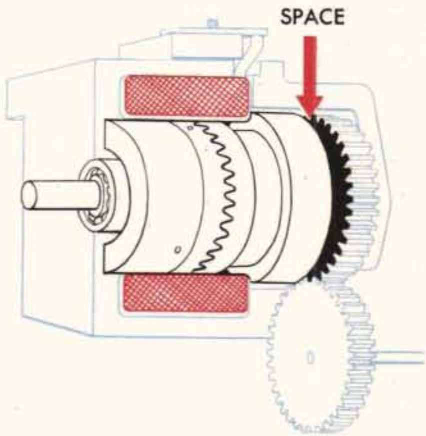
Three springs hold the sliding jaw out of engagement with the input jaw when the magnetic field is dead.

How the clutch works



When the current is OFF

There is no magnetic action. The springs hold the sliding jaw out of engagement with the input jaw. The input shaft and jaw may turn, but they have no effect on the output gear—*the two jaws are not connected.*

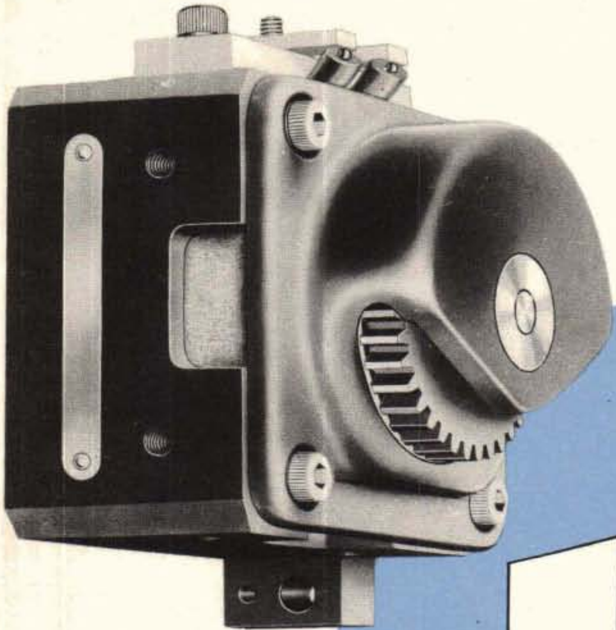


When the current is ON

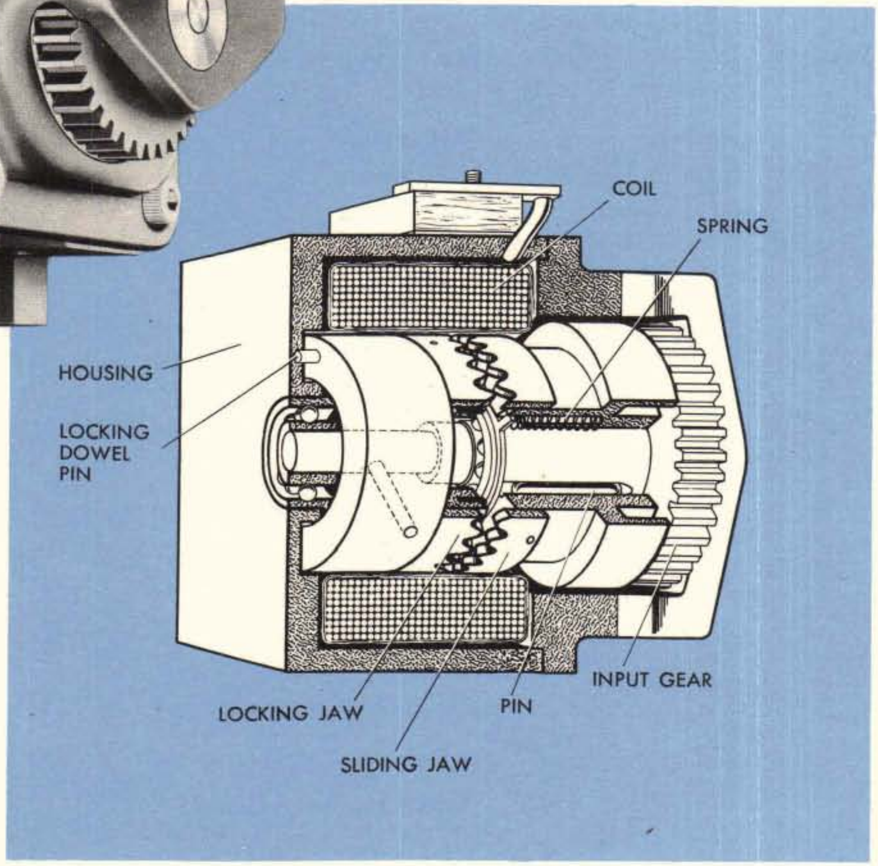
Both metal jaws become magnetized.

The opposite poles of the magnets attract each other. The sliding jaw is pulled into mesh with the input jaw and the two jaws turn together.

In this position, the output shaft will be driven by the input shaft.



The LOCK

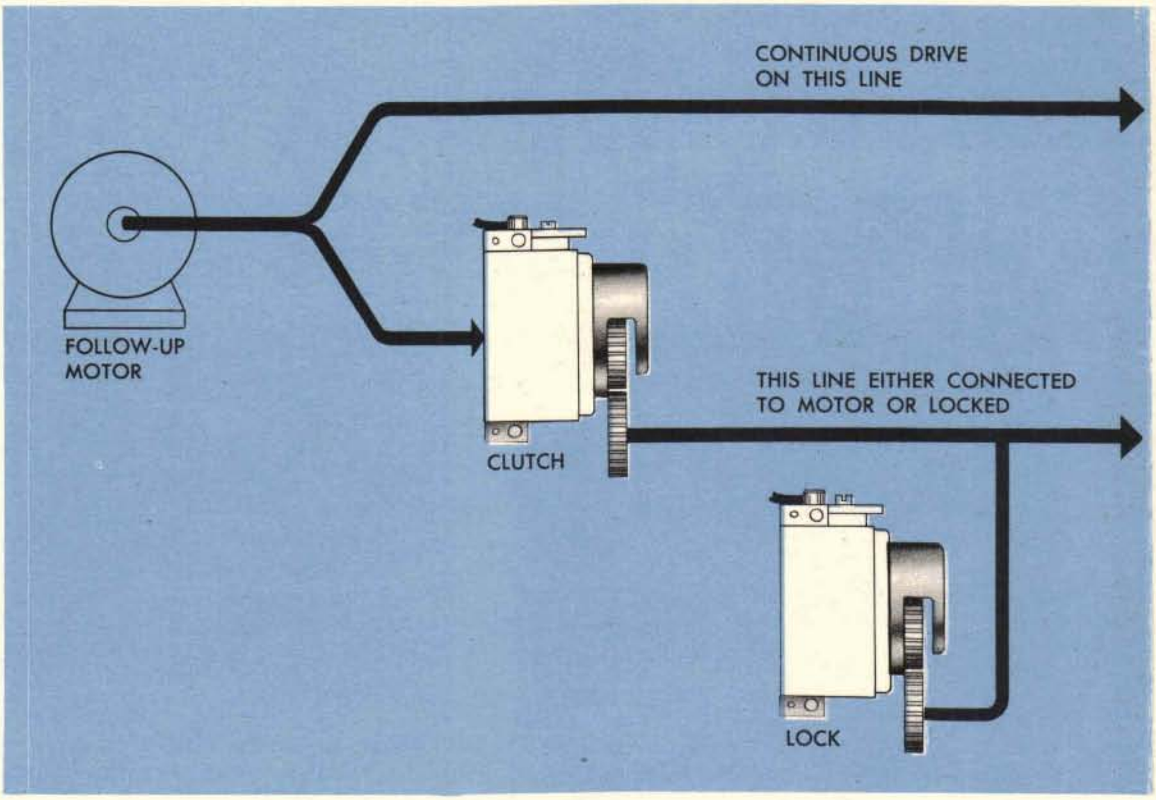


A LOCK is used to prevent a line of gearing from turning.

ON SCHEMATICS THE LOCK IS SHOWN THIS WAY

The solenoid lock works just like the solenoid clutch except that one of the jaws is locked to the housing by a dowel pin. The other jaw is attached to a gear, and is free to turn as long as the lock is de-energized. The gear is the *input* gear to the lock.

When the current is ON the two jaws are engaged. The whole shaft line connected to the input gear is then locked to the housing through the locking jaw.



How the clutch and lock work together

The clutch and lock are often used together. When a computer is switched from one type of operation to another, certain lines must be connected or disconnected, and the disconnected lines must be held in position while they are not being used.

Here is an example in which both a clutch and a lock are used on the same line. When the clutch is energized, the lock is de-energized and the motor drives the line.

When the clutch is de-energized, the lock is energized and the line is held stationary.

ELECTRICAL SWITCHES

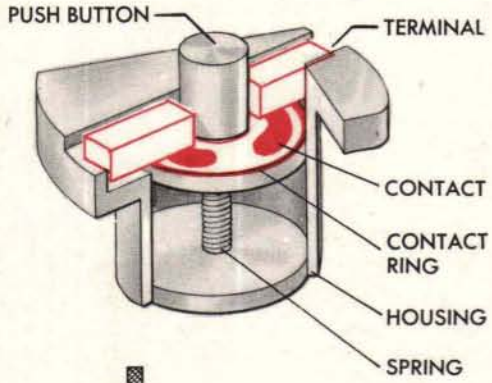
A switch is a mechanism which can make or break an electrical circuit.

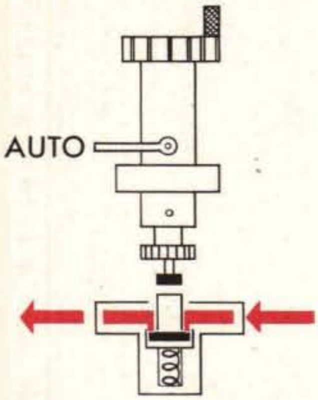
It must operate fast in order to prevent excessive arcing between terminals and contact points. Frequent arcing burns the metal and will soon cause either a poor contact or a complete break in the electrical circuit.

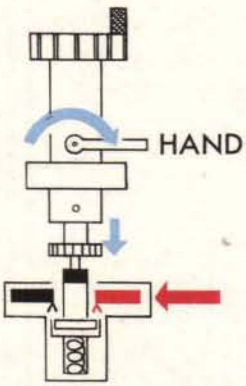
Switches have two main uses:

1. They turn the electrical power off and on.
2. They switch electrical power from one circuit to another.

The PUSH BUTTON SWITCH







The push button switch is a two-position switch for making and breaking an electric circuit.

It can only be used to turn power OFF or ON.

This switch consists of a housing containing a pair of specially shaped contacts, and a push button with a ring of contact material above its base.

The push button contact ring is held against the contacts by a spring.

The push button switch is usually operated by a two-position hand crank.

The two positions of the hand crank are usually for "automatic" and "hand" control.

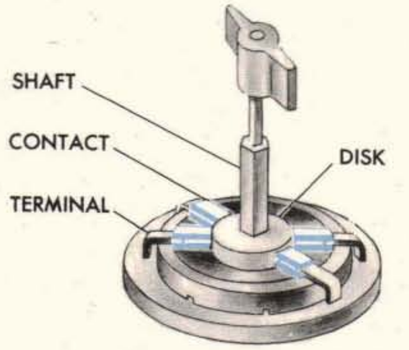
When the hand crank is set at AUTOMATIC, the switch-bolt is in its raised position.

The spring in the push button switch holds the contact ring against the contacts. The electric circuit is closed and the shaft line is positioned electrically.

When the hand crank is at HAND, the switch-bolt holds the contact ring down away from the contacts.

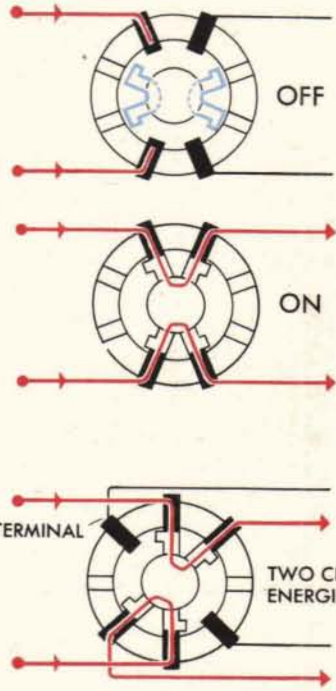
The electrical circuit is broken and the shaft line can be positioned by the hand crank.

The ROTARY SWITCH



A rotary switch can be used either as an ON and OFF switch or as a multiple switch, to change current from one circuit to another.

The ROTARY SWITCH used as an **ON and OFF switch.**



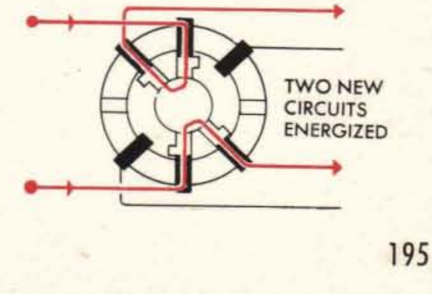
The shaft of the rotary switch is controlled by a spring and detent arrangement which allows the shaft to make only a quarter turn at a time. As the switch is turned the spring is tightened and then suddenly released, so that the shaft snaps around and makes its quarter turn very fast.

Around the base of the switch are two pairs of terminals. The shaft going through the center of the switch carries a pair of double contacts mounted in a disk.

When the switch is OFF the contacts are away from the terminals and the circuit is broken.

When the switch is ON, the shaft turns a quarter turn bringing the contacts against the terminals. The circuit is made.

The ROTARY SWITCH used as a **MULTIPLE switch.**

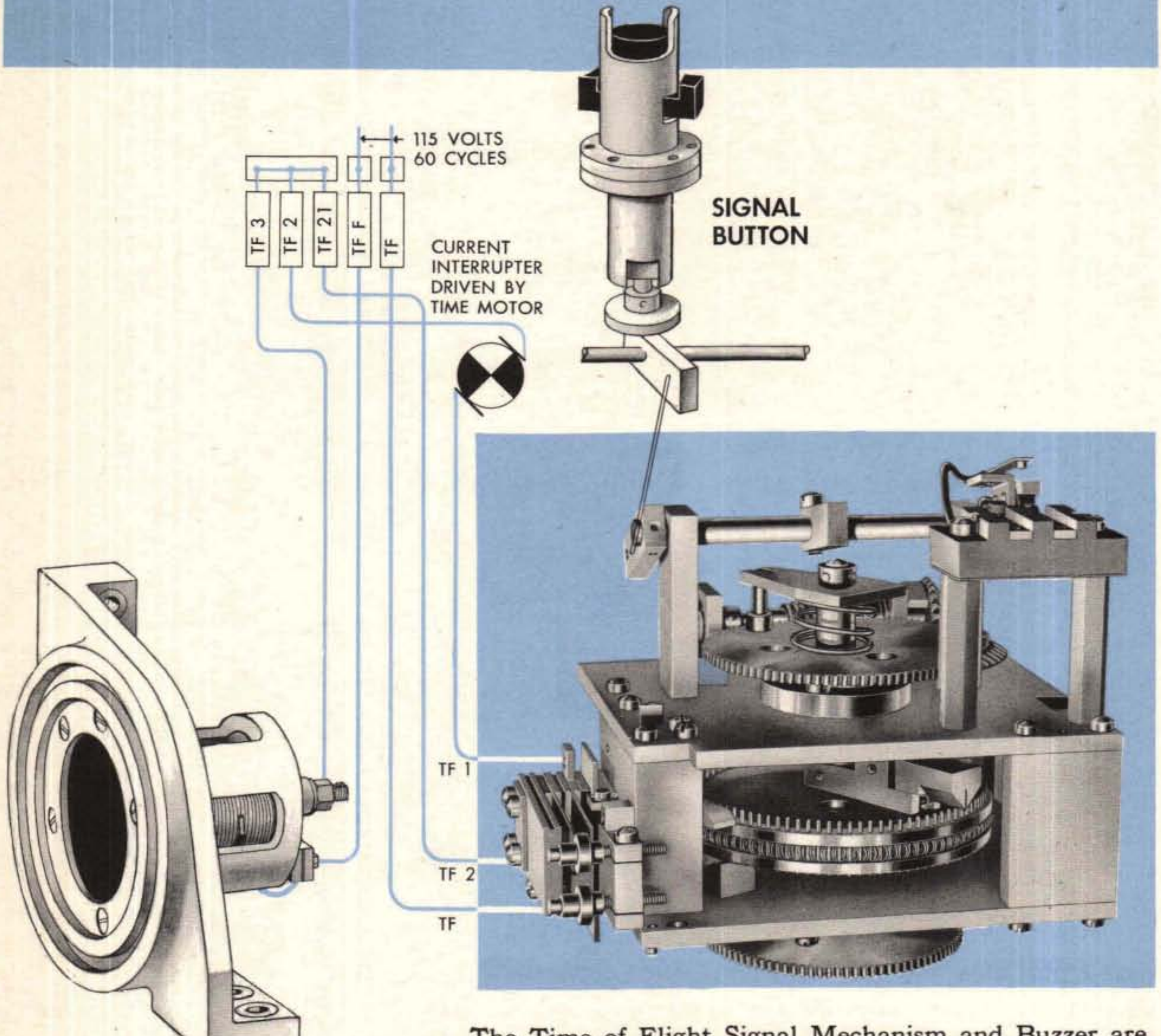


When the rotary switch is used to change current from one circuit to another, it has a different detent arrangement so that the shafts and contacts only move ⅛ of a revolution when the switch is turned.

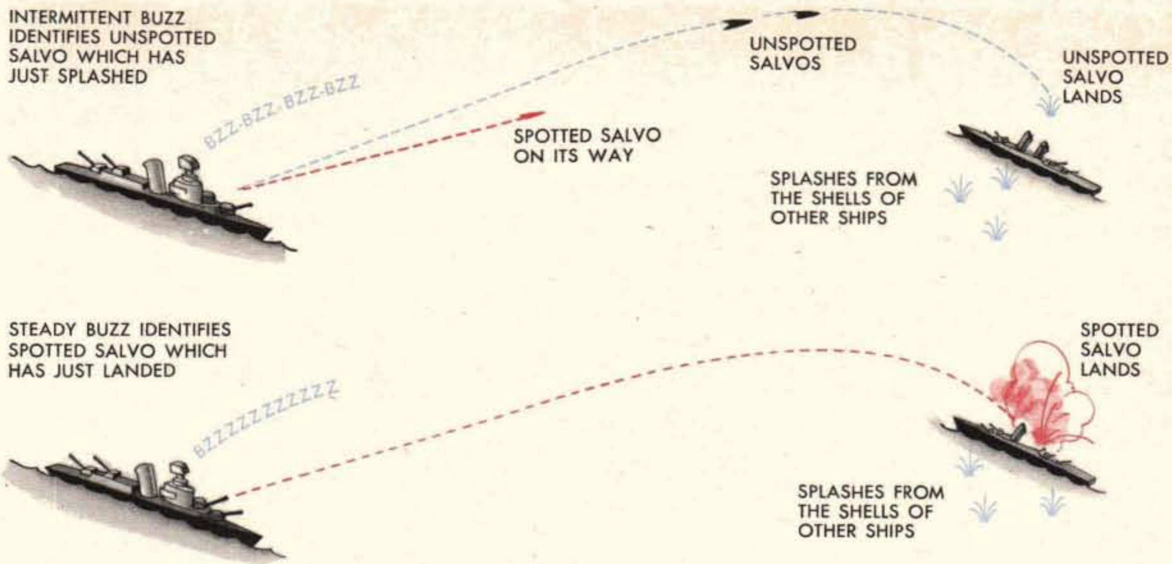
By making ⅛ of a turn, the contacts change the flow of current from one circuit to another.

These two positions of the contact points represent two switch positions, such as "Automatic" and "Semi-automatic." When other positions are needed, the switch can be built up in layers of contact points and terminals—to accommodate the additional positions.

TIME OF FLIGHT
signal mechanism and buzzer



The Time of Flight Signal Mechanism and Buzzer are used with several of the main battery Range Keepers. They enable an observer to identify any particular salvo. The signal mechanism sounds a buzzer at the observer's station which tells the observer when the salvo in which he is interested is about to land.



There are at least two reasons why observers are interested in particular salvos:

1 Shells from other ships may be landing around the target. The observer must single out the splashes of one of the salvos from his own ship in order to find out how close to the target his shells are landing.

2 From observation of shell splashes the observer estimates the deflection and range spot corrections which he will need to put the shells on the target. The important thing in spot correcting is to keep track of the particular salvo which has been spot-corrected in order to observe the effect of the spots.

Unless the observer knows which salvo has been spot-corrected, this may happen:

The observer calls for a set of spots.

Meanwhile several salvos on which the spots have not taken effect have been fired and are in the air.

These unspotted salvos miss and the observer, seeing their splashes, thinks his first spots were not large enough and overspots.

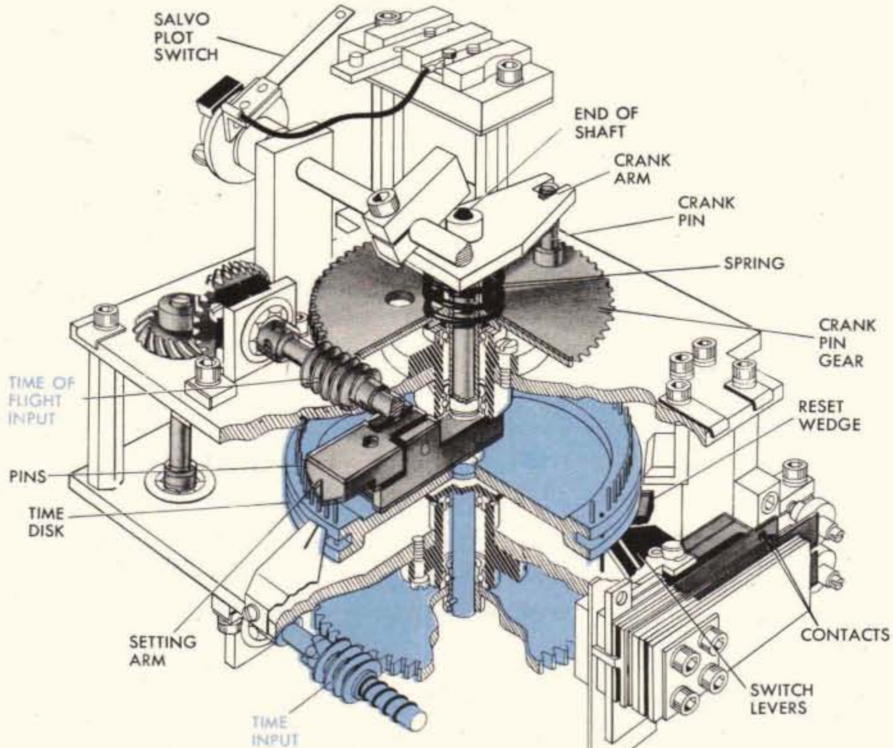
With a time of flight mechanism, it is easy to keep track of any particular salvo, because the same value of time of flight that goes into the gun order is used to time the buzzer.

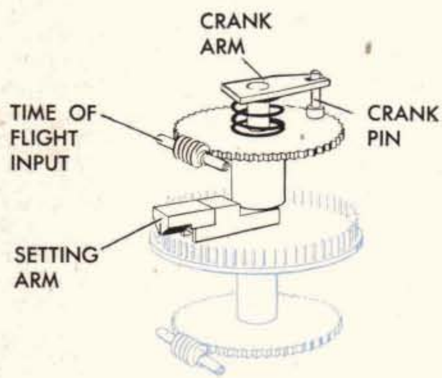
When the salvo is fired, the *Time of Flight Button* is pressed to set the signal mechanism. The signal mechanism sounds the buzzer just before the shells land.

An interrupted buzz identifies a salvo which has *not* been corrected by spots.

A steady buzz sounds for a spotted salvo.

Here is the TIME of FLIGHT MECHANISM





TIME OF FLIGHT and TIME feed into the signal mechanism continually, whether the signal mechanism is being used to sound the buzzer or not.

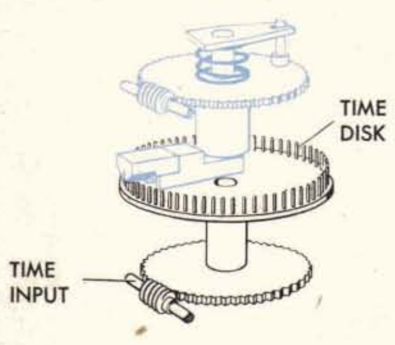
The TIME OF FLIGHT input

Time of Flight from the *Tf* ballistic cam comes in continuously through a worm that turns the gear on which the crank pin is mounted.

The crank pin extends up through a notch in the crank arm and turns the crank arm.

The setting arm is mounted on the same shaft as the crank, so that when the crank is turned the setting arm turns with it.

In this way TIME OF FLIGHT POSITIONS THE SETTING ARM.



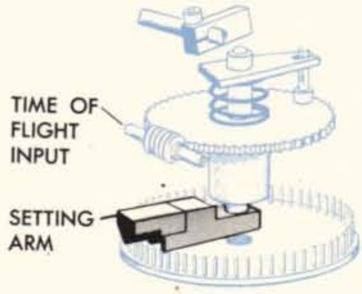
The TIME input

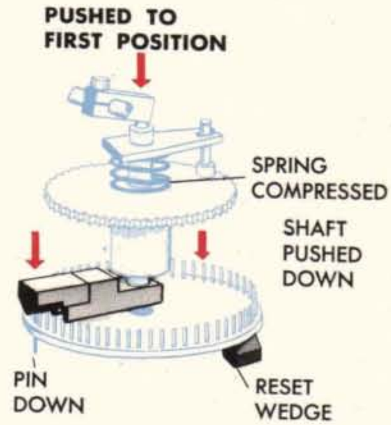
Time from the time motor comes in through a worm which rotates a gear on the lower shaft. This same shaft carries the time disk around. The time disk rotates all the time at a constant speed.

This disk holds pins closely spaced at equal intervals around its rim.

These two inputs keep the signal mechanism in constant readiness to receive a setting from the TIME OF FLIGHT SIGNAL BUTTON.

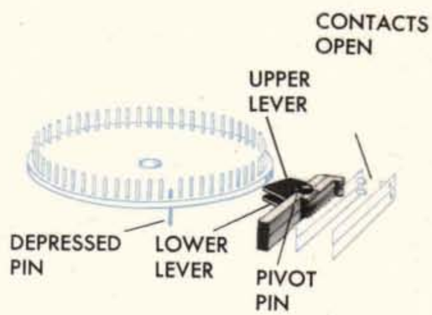
and here is how it works



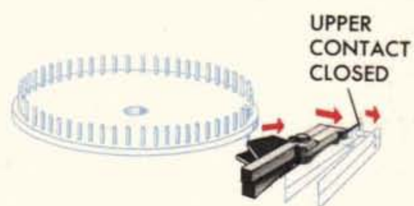


The *Time of Flight* signal button moves the setting arm down.

A spring returns the setting arm.

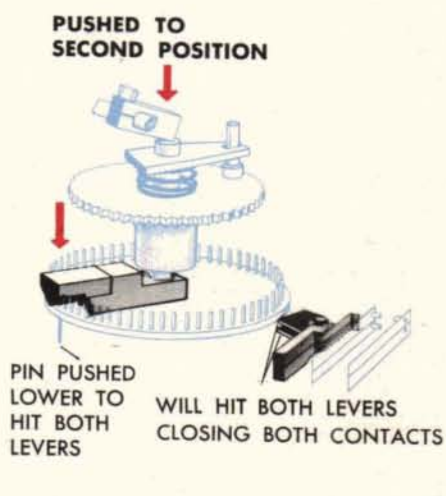


When the button is pressed, the arm pushes down the nearest pin on the moving time disk.



As the time disk rotates, the pin which was pushed down is carried around until it hits the upper lever, closing the upper contact to the switch.

The switch closes the circuit to one or more Time of Flight buzzers and an *interrupted buzz* results.

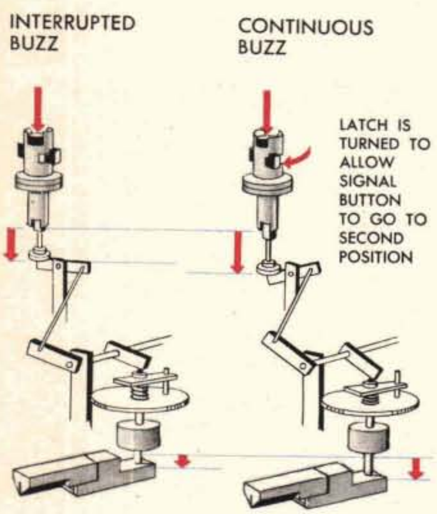


However, when it is necessary to distinguish a salvo which has been spot corrected, the button is pushed further, making the arm push one of the pins *lower* than in normal operation.

The pin in the *lower* position engages *both* levers, which close both contacts to the switch. A *continuous buzz* results.

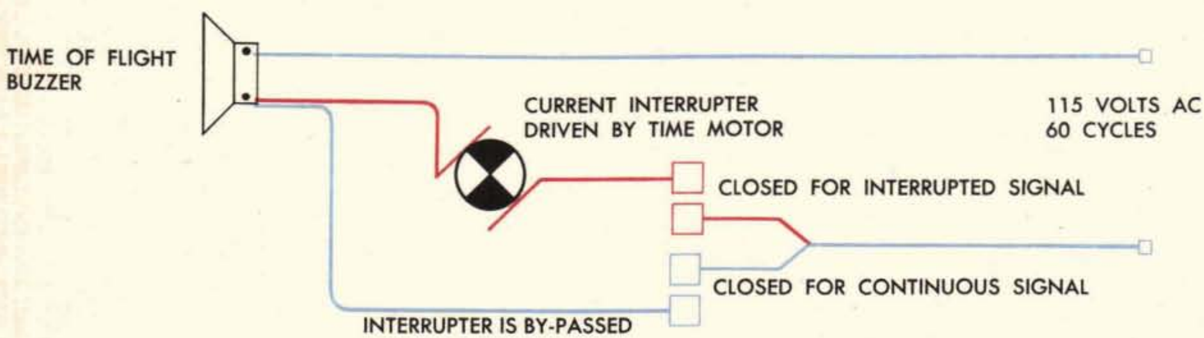
After passing the switch levers the pin is carried over the reset wedge which pushes it up to its original position.

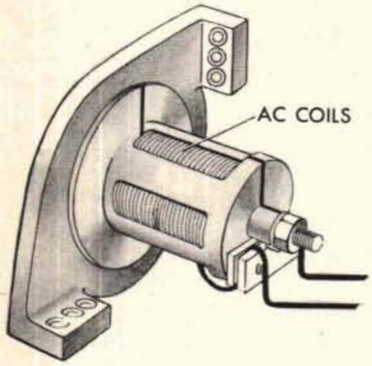
The two kinds of buzzes: interrupted continuous



The interrupted buzz is used to identify salvos which have not been spot-corrected. It is produced by sending the current through an interrupter which alternately opens and closes the circuit. The upper contacts make the connection to the interrupter. When the lower contacts are also closed, the current bypasses the interrupter to produce a steady buzz.

The Time of Flight signal button has two positions. The first position lowers one of the pins enough to trip the upper contacts, and send the current through the interrupter. The second position pushes the pins low enough to close *both* sets of contacts and bypass the current around the interrupter.





The Time of Flight BUZZER

The buzzer works through a solenoid. The solenoid is connected across a 115-volt 60-cycle *AC* circuit. The alternating current causes a plunger to vibrate back and forth.

The plunger vibrates the diaphragm and it is this vibration which produces the buzzing sound.

The TIME of FLIGHT mechanism in ACTION

If the Time of Flight signal button is pressed when the salvo is fired, the buzzer will sound just before the splashes are visible.

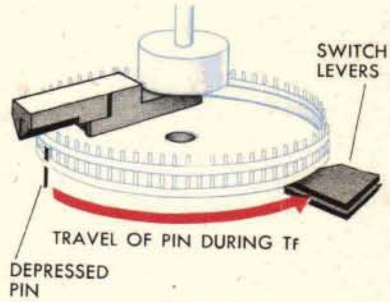
The length of time which elapses between the pushing of the button and the sounding of the buzzer depends on the *distance* the pin has to travel from the time it is depressed until it touches the lever.

The setting arm is positioned by Time of Flight and it depresses the pin at the beginning of Time of Flight.

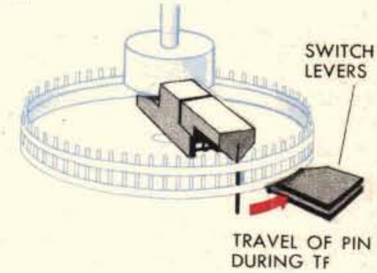
The pin is carried by the time disk, which is always turning at a constant speed independent of the setting arm.

So the distance the pin has to travel from the time it is depressed until it touches the lever corresponds to Time of Flight, Tf.

Here Time of Flight is quite long ... The depressed pin must travel quite a distance to reach the lever which closes the switch and causes the buzzer to sound.

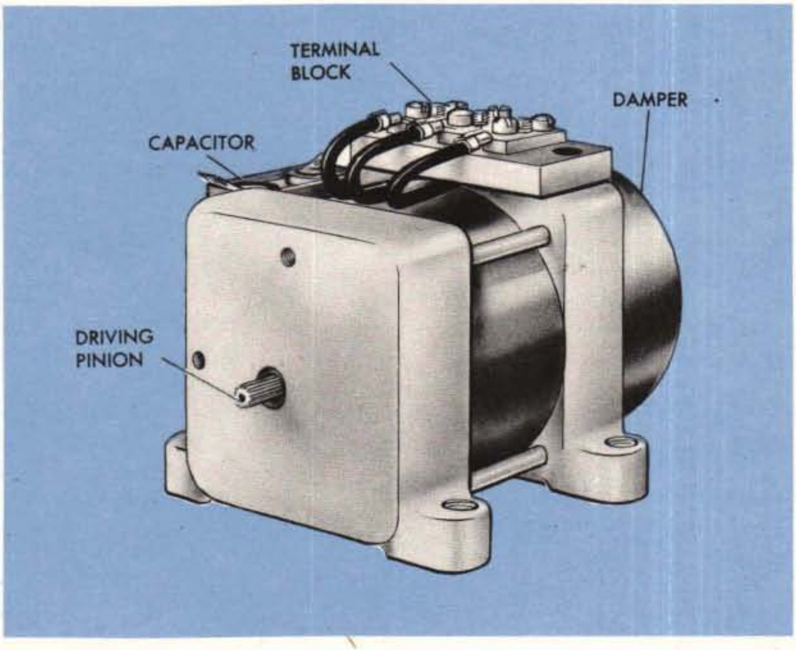


Here Time of Flight is short ... Notice that the depressed pin must travel only a short distance to reach the lever which closes the switch.

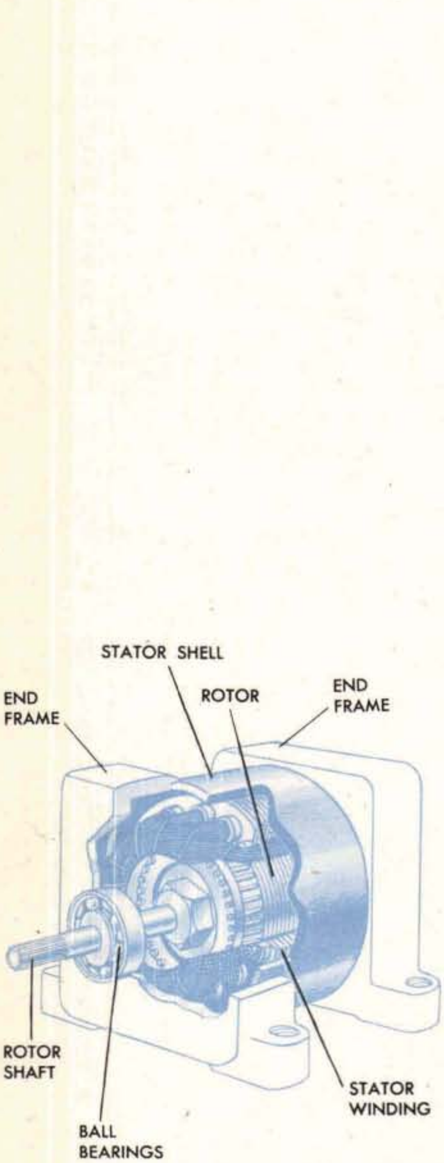


It is easy to see how the angular position of the arm which depresses the pin controls the distance the pin must travel to the switch lever. This angular position is set in by Time of Flight. Therefore, the distance traveled is proportional to the Time of Flight, except for a slight advance to allow the signal to precede the splashes.

SERVO MOTORS



The various mechanisms in a Computer, such as component solvers, vector solvers, and multipliers do not have outputs powerful enough to position heavily loaded shafts. Outputs from such mechanisms often merely control the action of electric servo motors, and these motors do the actual positioning.



The servo motor is an induction type motor. That is, the rotor is not connected directly to the power supply, but has current "induced" in it by the action of a magnetic field. This field is produced by the stator coils when 115-volt *AC* current is supplied to them.

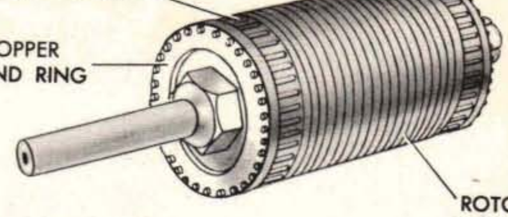
The induced current in the rotor creates its own magnetic field, and as this field strives to "line up" with the rotating stator field, the rotor is made to revolve. (See page 342.)

The servo motor consists of four major parts: Two end frames
A Rotor
A Stator

The rotor shaft runs in ball bearings mounted in holes in the end frames.

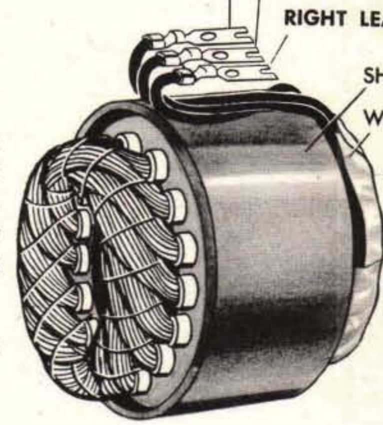
The ends of the stator shell fit into the end frames, and four bolts hold the assembly together.

One end of the rotor shaft can either be cut to form a pinion, or a pinion can be mounted on it. The opposite end of the shaft often carries a "damper."



Rotor

The rotor is of the squirrel cage type, consisting of a number of iron disks. Each disk is pierced with holes around its circumference, and through these run copper rod conductors. The ends of these conductors are joined to copper end rings. Neither brushes nor slip rings are required.



Stator

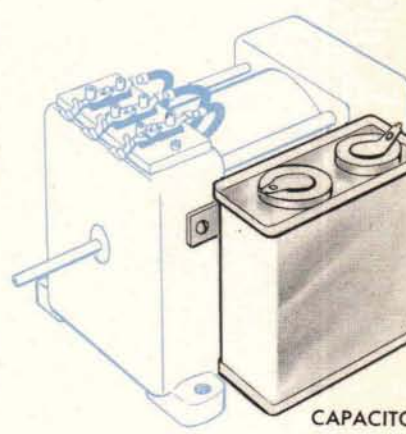
The stator consists of a cylindrical shell with slots in which the field coils are placed. There are two field coils, joined together at one end to provide a common lead to a single terminal. The other ends are left free, so that they can be led to the outer contacts of a follow-up control. The common, or center, lead is marked *C*, and the outer leads *R* and *L* (right and left).

The three leads from the stator are brought to a terminal block.

Capacitor

If no capacitor were used, and both coils of the stator were connected directly across the power supply line, the rotor of a servo motor would not revolve, but would merely remain stationary, unless actually given a push in either direction. Without a capacitor this type of motor has no starting torque of its own.

However, when current from the supply line is made to pass through a capacitor before it can reach one of the coils (while the other coil remains connected directly), the rotor will revolve. The direction of rotation will depend on which coil is supplied through the capacitor. (See page 345.)

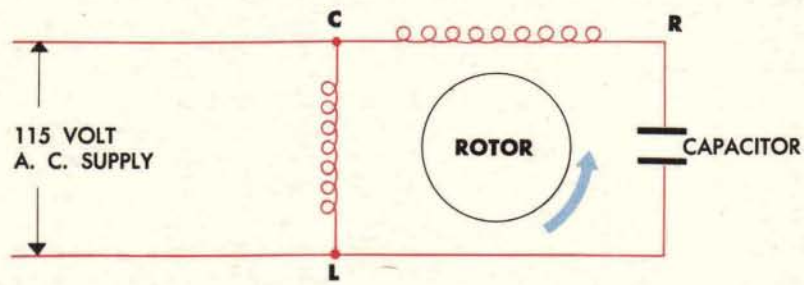


Capacitors of various sizes are used with each type of servo. However, capacitors cannot be interchanged at will. For each particular servo installation in a computer, only one particular capacitor is specified. When a capacitor is replaced, the new capacitor should be the size specified for the given installation. USE ONLY THE PARTICULAR CAPACITORS SPECIFIED FOR EACH SERVO INSTALLATION.

The capacitor is usually mounted on the side of the motor.

A servo motor must drive

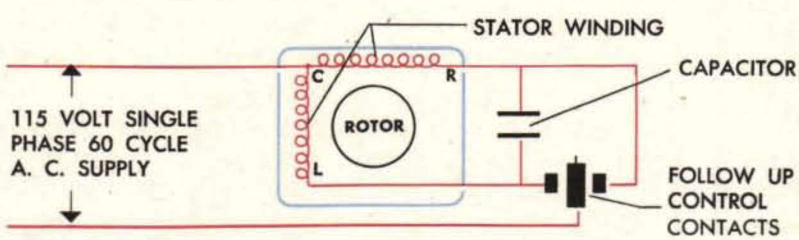
A servo motor could be connected as shown here. The *C* and *L* leads are connected directly to the power supply which puts one coil of the stator winding directly across the supply circuit. The third lead (*R*, in this case) is connected to the supply through a capacitor so that the second coil of the stator winding is connected to the supply in series with the capacitor. This arrangement produces a drive in one direction.



Although rotation of the servo motor rotor can be obtained by putting the proper capacitor in the circuit, rotatio of the rotor in one direction only is not enough. A servo motor must be able to reverse direction, in order to position shafting in response to signals of either increasing or decreasing values.

To make the servo motor able to drive in either of two directions, contact points, as shown in the diagram, are introduced into the circuit.

THE COMPLETE SERVO MOTOR HOOK-UP CAN NOW BE SHOWN LIKE THIS:



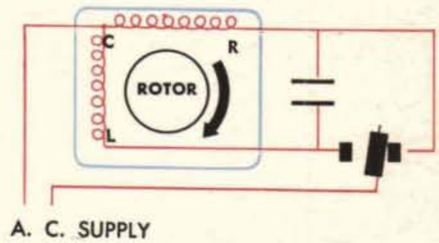
One side of the supply circuit is connected to the *C* lead at the terminal block on the motor frame, the other is connected to the inner contact on the central arm of a follow-up control. Ends *L* and *R* of the stator coils are connected to the outer contacts of the follow-up control.

The follow-up control acts to bring either the *L* or *R* contact against the center contact according to the direction the motor must drive.

in either of two directions

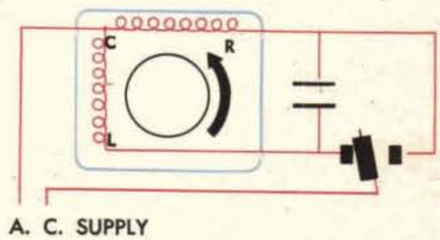
Clockwise rotation

When the follow-up control completes the circuit through the righthand outer contact, the 115-volt supply is connected directly across the *R-C* leg of the stator winding, and current flows through the *R-C* coil. Current also flows through the *L-C* leg of the stator winding, but in doing so passes through the capacitor. The effect of the capacitor is to make the current in the *L-C* leg lead the current in the *R-C* leg. This results in the rotor being pulled around in a clockwise direction.



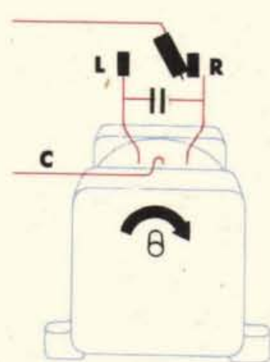
Counterclockwise rotation

When the follow-up control reverses the contacts the 115-volt supply is connected directly across the *L-C* leg of the stator winding, and the current flowing through the *R-C* leg has to pass through the capacitor. Under these conditions, current in the *R-C* leg leads that in the *L-C* leg, and the motor is rotated counterclockwise.



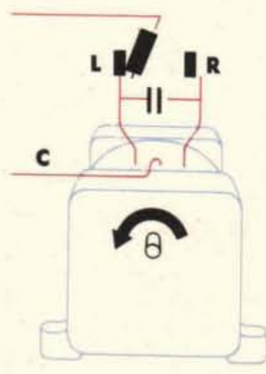
Looking at the motor from the end where the stator leads come out, the action can be illustrated as shown here:

When the follow-up completes the circuit through the outer contact connected to *R*, the rotor rotates clockwise.



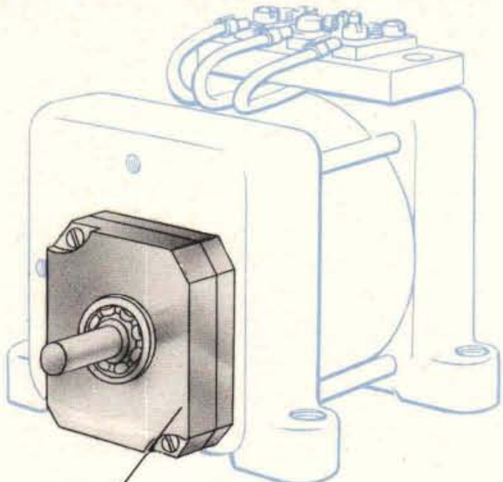
When the follow-up completes the circuit through the outer contact connected to *L*, the rotor rotates counterclockwise.

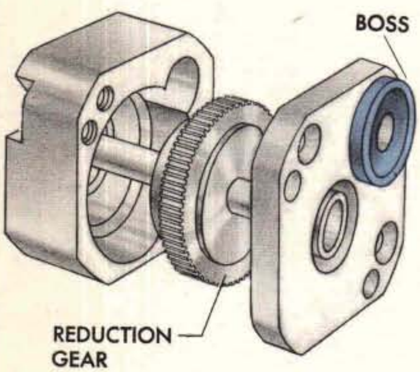
Although there are minor variations, all servo motors are essentially the same. All are required to start and stop quickly, and drive in either direction.



Instrument servo motors are so designed that they may be left energized with the driven shafting held against a limit stop (and the rotor thus held "locked") for an indefinite period without serious damage to the motor.

REDUCTION GEAR



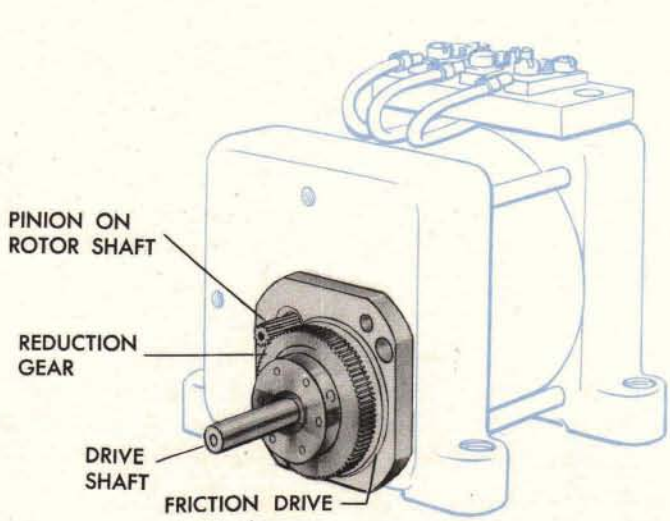


In some instances, the servo motor drives through a reduction gear.

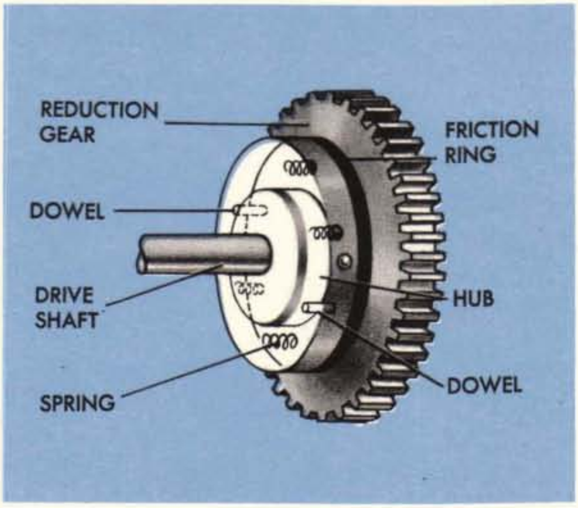
The reduction gear assembly consists of a housing in which a spur gear is mounted. In one corner of the back plate of the housing is a hole around which a boss is fitted.

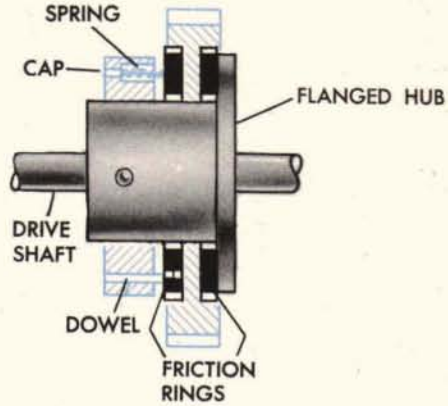
The boss fits exactly into the bearing hole in the end frame of the servo motor, positioning the spur reduction gear so that it meshes properly with the pinion on the servo rotor shaft.

The reduction gear assembly can be secured to the end frame in any one of four corner positions. This permits shifting the drive shaft to suit any particular gear connection which may be required for a particular installation.



FRICTION RELIEF

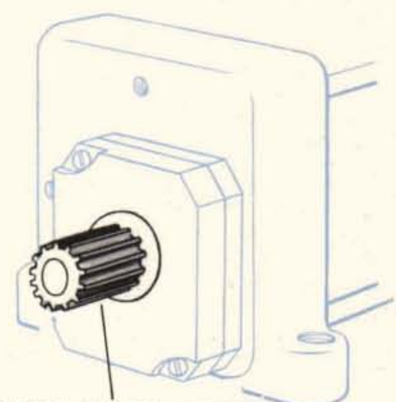




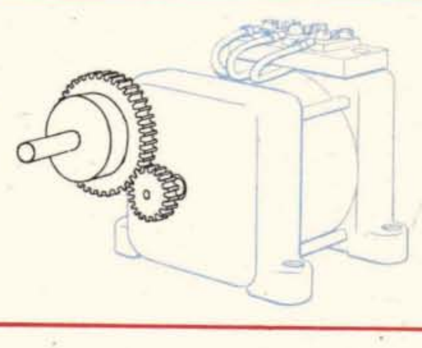
The motor drive output is transmitted through a friction relief.

On the shaft is a flanged hub. Over this hub is placed the reduction gear and two friction rings of tough but somewhat resilient material known as "phenolite." To the hub is fastened a metal cap which is drilled to hold four springs. These springs press against one of the friction rings keeping the rings and reduction gear tightly against the flange. Two dowels passing through the cap and the friction ring keep the ring rotating with the cap and shaft. Under normal loads, the drive is transmitted by the reduction gear through the grip provided by the friction rings acting under spring pressure. When the load becomes abnormal, as when the rotor shaft is suddenly stopped by a limit stop, the reduction gear slips against the rings. This slippage prevents shock, and prevents undue strain on gears, shafting, and mechanisms.

A pinion mounted on the drive shaft, outside of the housing, transmits the motor drive to other mechanisms.



The reduction gear (with friction relief) need not be mounted in a housing on the motor frame. It is often mounted externally, as shown here.

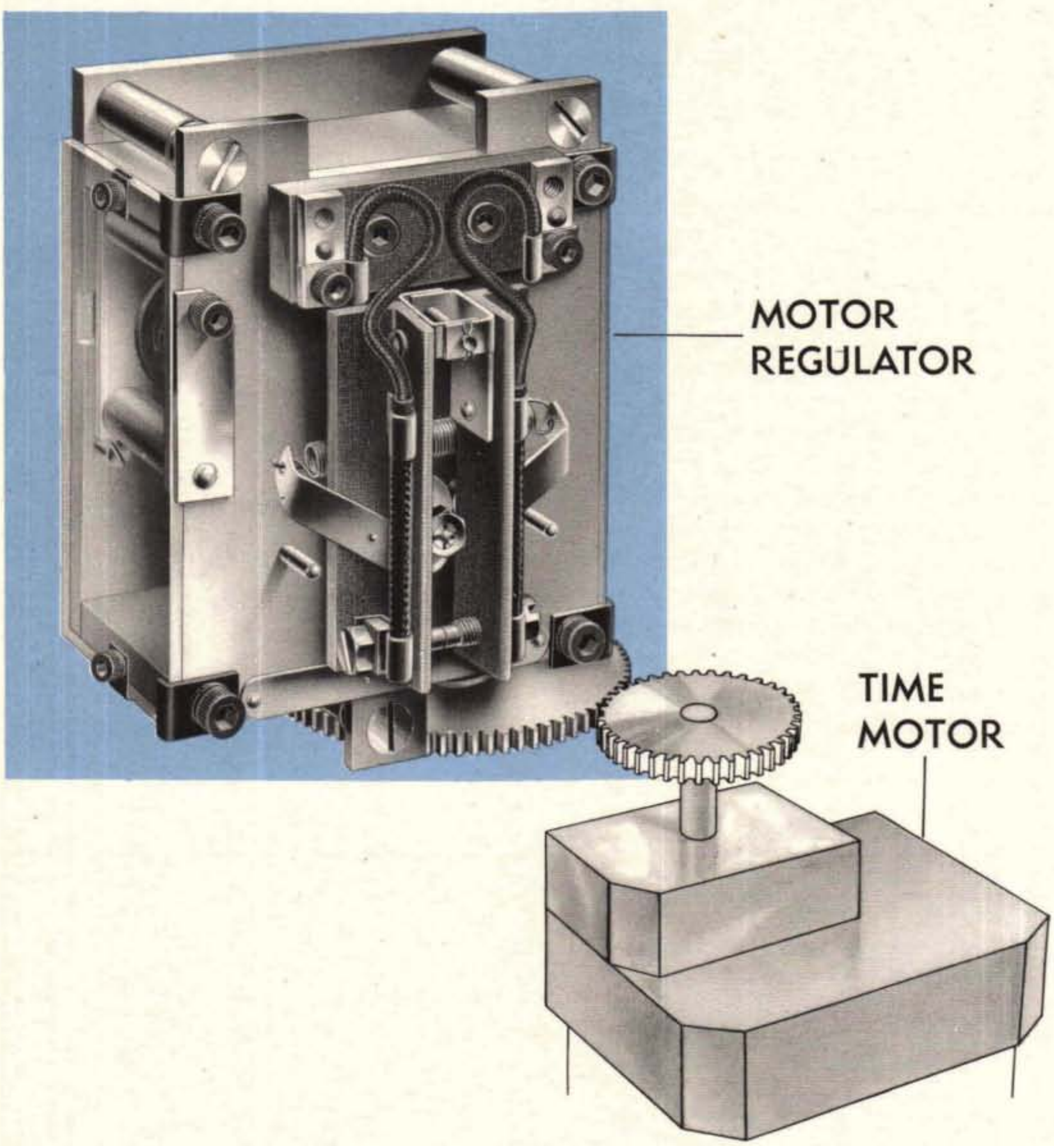


MOTOR REGULATOR

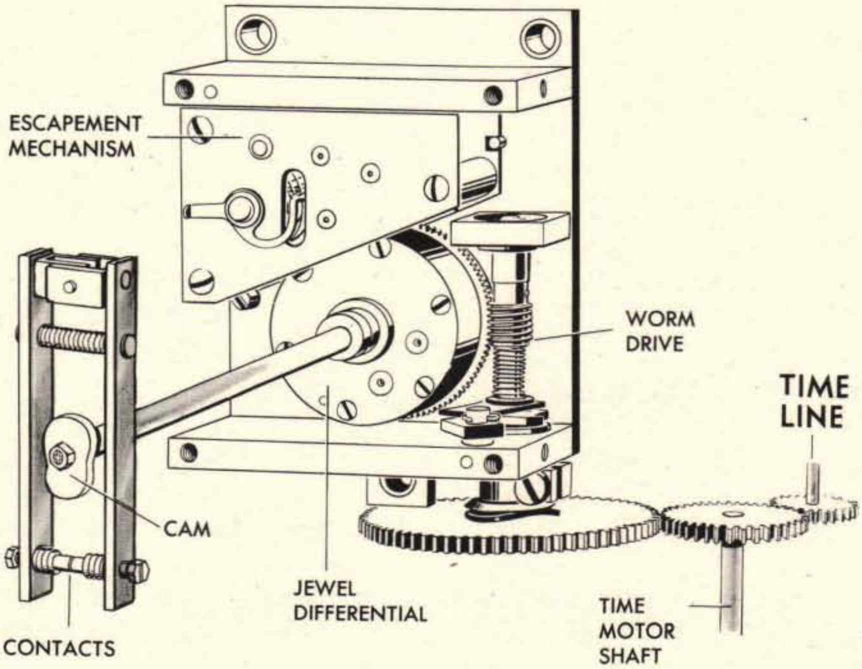
The rotation of some of the integrator disks represents TIME. They must be driven by a "time motor" at a *constant speed.*

The motor regulator is a device for keeping the time motor running at a constant speed, independent of variations in the load.

The time motor is geared to turn the "time line" too fast if power is supplied to it continuously. The motor regulator breaks the circuit when the motor begins to go too fast, and closes it again when the motor slows down, so that the motor speed is practically constant.



Here's the mechanism without its case



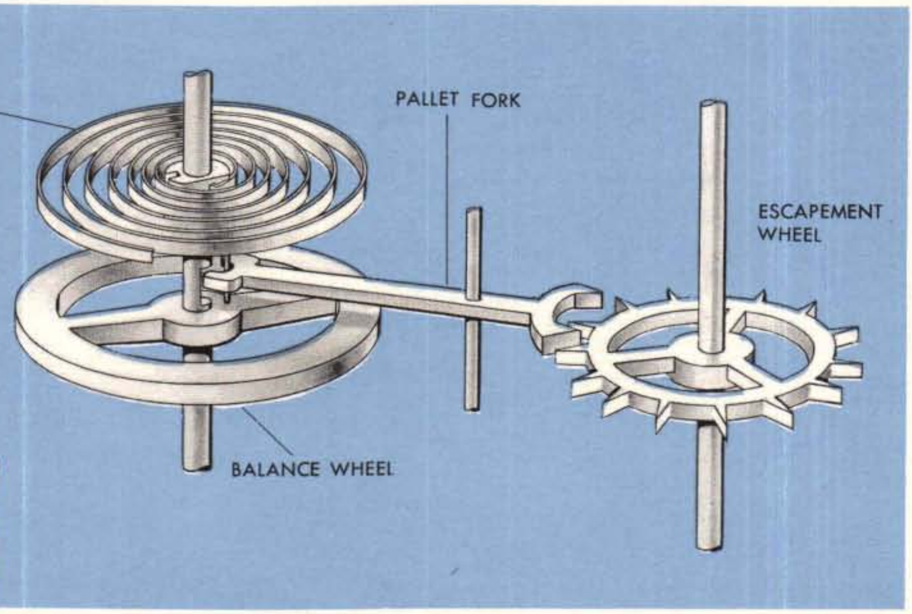
There are three main parts:

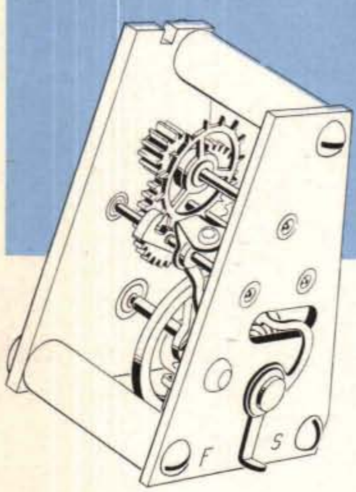
1 The Jewel Differential
2 The Escapement Mechanism
3 The Cam and Contact Assembly

The worm drive transmits the rotation of the motor shaft to the spider of the differential.

The differential compares the motor speed with the constant escapement speed. When the motor drives the spider faster than the escapement, the difference turns the cam between the arms of the "make and break" contacts.

What makes the REGULATOR tick





The schematic picture of the escapement mechanism has been simplified by the omission of a locking disk and limit stops which prevent the pallet from swinging too far.

The ESCAPEMENT MECHANISM

The escapement mechanism works like the escapement in a watch. The principal parts are the escapement wheel, pallet, balance wheel and hair spring.

The escapement wheel is the input.

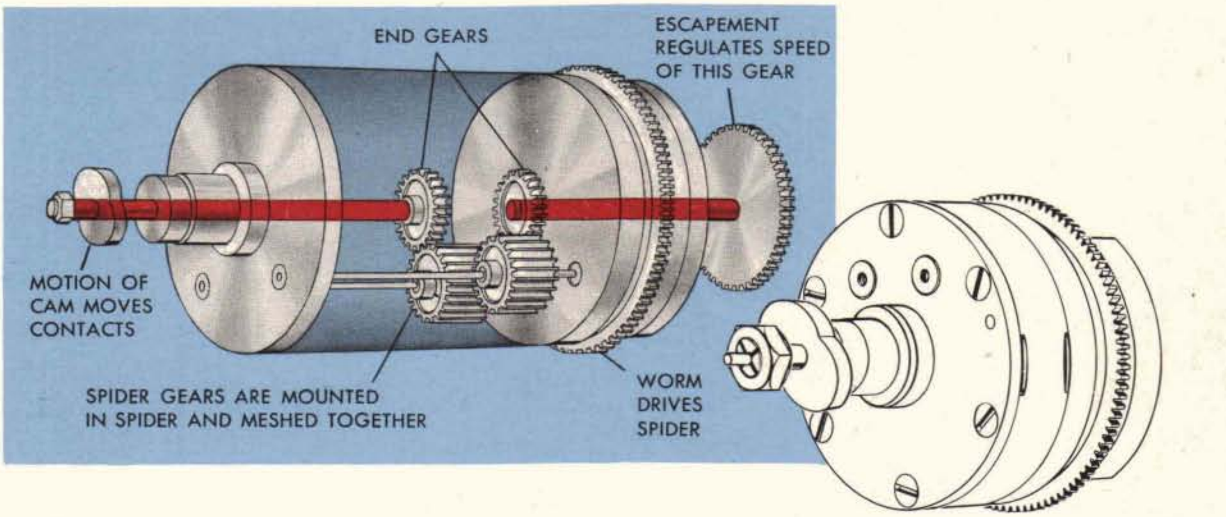
Rotation of the escapement wheel swings the pallet around its pivot staff until it locks against a tooth in the escapement wheel.

As the pallet swings it moves the pin in the balance wheel. This movement rotates the balance wheel and winds up the hair spring.

Winding the hair spring slows up, stops, and then reverses, the rotation of the balance wheel. The pin in the balance wheel now swings the pallet in the opposite direction.

This opposite pallet movement allows the locked escapement wheel tooth to escape and the cycle is repeated.

The pallet movement is controlled by the even rhythm of the balance wheel and hair spring. This rhythm holds the escapement wheel input to a constant average speed.



The JEWEL DIFFERENTIAL

This spur gear differential is known as a jewel differential because the gears run on jewel bearings. The jewel bearings reduce friction drag to a minimum.

The spider in this differential is a housing that encloses the end gears and spider gears. This spider is driven by the time motor through a worm input.

One side of the differential is geared to the escapement mechanism. The other side drives the cam.

When the motor is running, the spider turns and drives the side of the differential geared to the escapement mechanism.

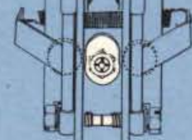
The escapement mechanism tends to turn at a CONSTANT speed. The motor speed varies. The *difference* between these speeds drives the output side of the differential and turns the cam.

The cam turns between two rollers on the arms holding the contacts. These arms are held together by a spring.

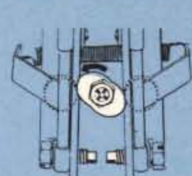
When the MOTOR SPEED IS *GREATER* THAN THE ESCAPEMENT SPEED, the cam turns and spreads the contact arms. This OPENS THE CONTACTS, and the motor slows down.

When the MOTOR SPEED IS *LESS* THAN THE ESCAPEMENT SPEED, the cam turns the other way, returning to its up-and-down position. The SPRING ON THE CONTACT ARMS CLOSES THE CONTACTS. The motor speeds up again.

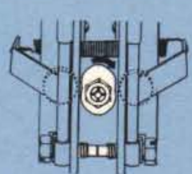
1 CAM IS VERTICAL. CONTACTS ARE CLOSED WHEN MOTOR IS TURNED ON.

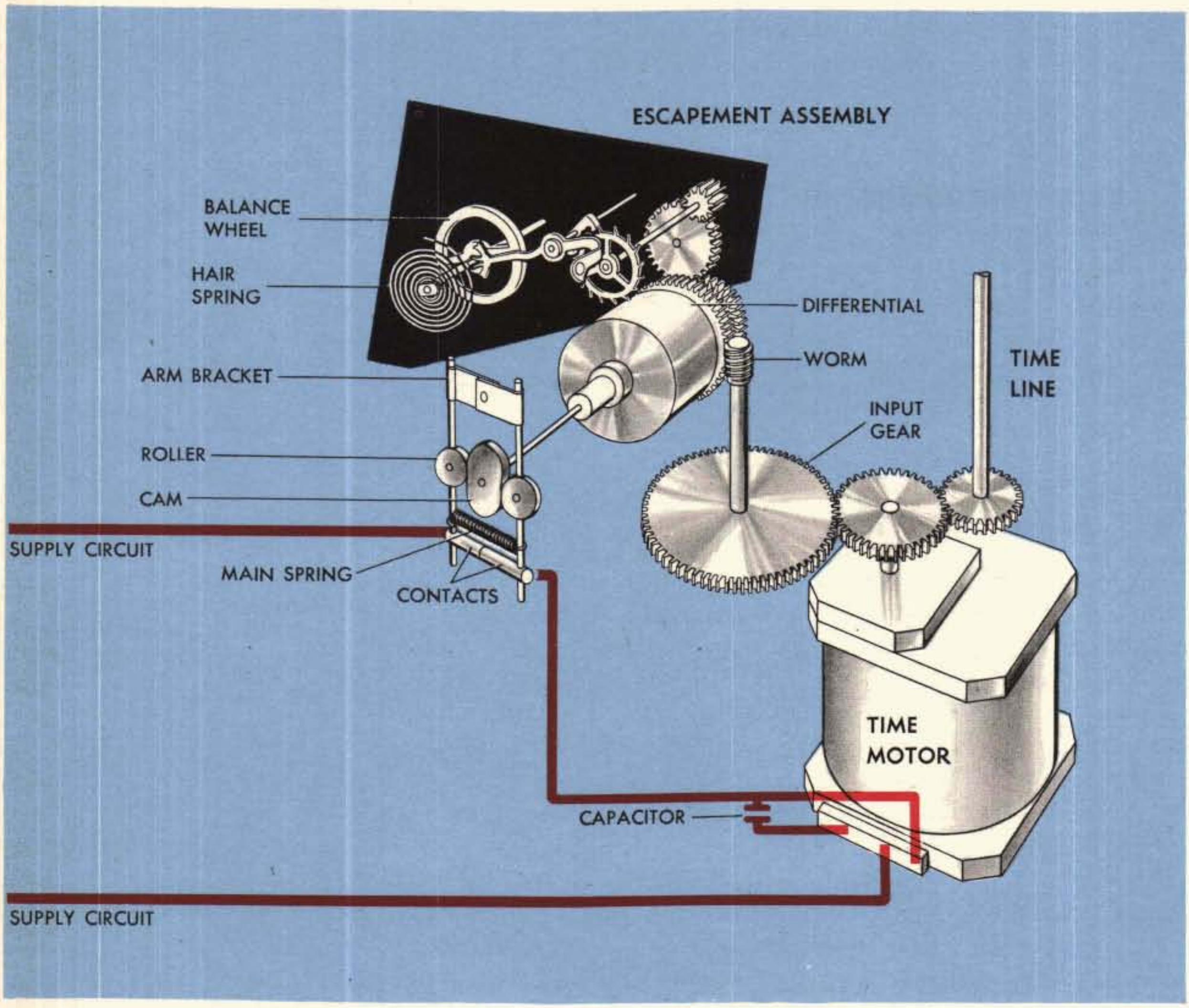


2 MOTOR SPEED IS GREATER THAN ESCAPEMENT SPEED. CAM TURNS. CONTACTS OPEN AND MOTOR SLOWS DOWN.



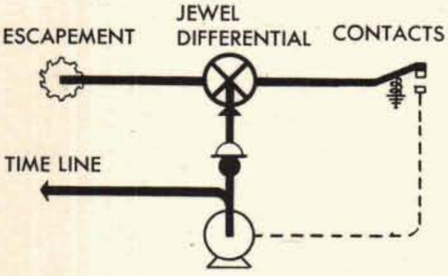
3 MOTOR SPEED IS LESS THAN ESCAPEMENT SPEED. CAM RETURNS TOWARD VERTICAL POSITION. CONTACTS CLOSE AND MOTOR SPEEDS UP.





Here's how it works

Here is the motor regulator unit hooked up with the time motor. When the motor is turned on, the following things happen almost instantaneously:

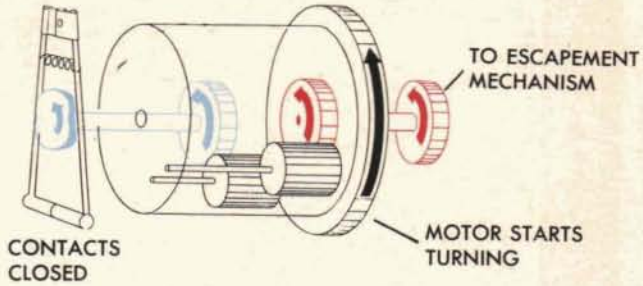


1. Since the contacts are closed, current goes through them to the time motor.

2. The worm on the input shaft turns, driving the spider of the differential.

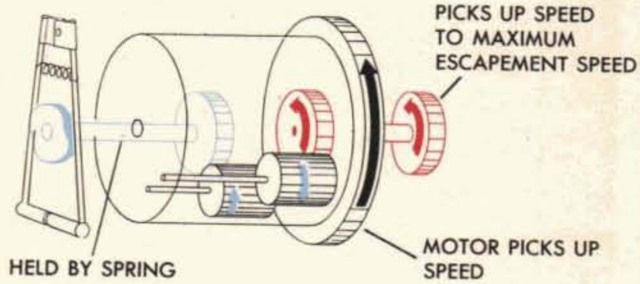
3 The cam begins to turn.

4 Almost immediately the cam hits the rollers on the contact arms. The spring acts as a slight brake so that the contacts do not open at once.

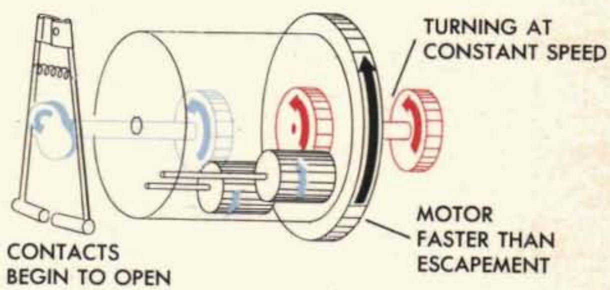


5 Following the line of least resistance, the motion from the spider backs into the escapement mechanism which picks up speed.

6 Meanwhile the time motor has been picking up speed. Soon the escapement mechanism is moving at the maximum speed that the coiling and uncoiling of the hairspring will allow.

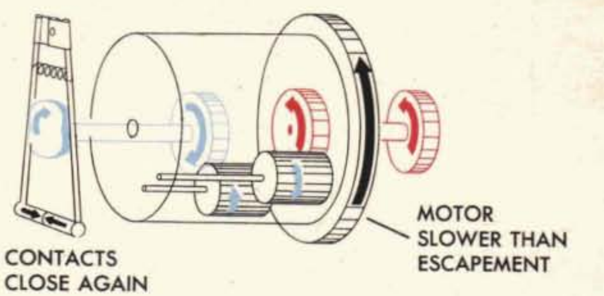


7 When the rotation of the spider can no longer back into the escapement, it turns the other side of the differential on which the cam is fastened. The contacts open.



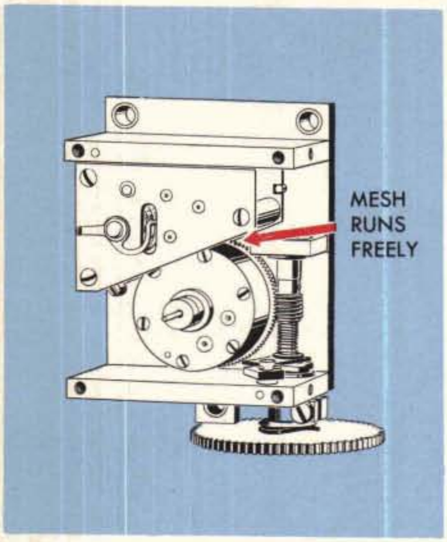
8 The motor slows down a little.

9 As soon as the motor speed falls a little below the escapement speed, the cam will no longer hold the contacts apart. The mainspring will bring the arms together, turning the cam toward its vertical position and bringing the contacts together once more. The cycle then starts over again.



The cam is continuously opening and closing the contacts as the motor speed becomes slightly greater or less than the escapement speed.

This happens so fast that the motor speed is always closely matched with the escapement speed. *The average speed of the motor output shaft is constant.*



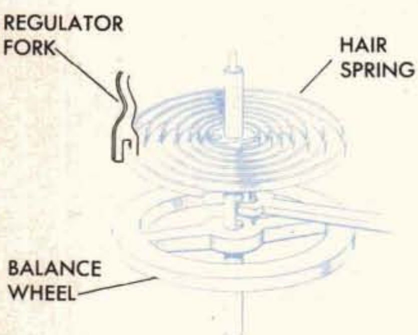
Adjusting the MOTOR REGULATOR

Before any individual part of the Motor Regulator is adjusted, check the complete Motor Regulator Unit. In this way, trouble that would require replacement of all or part of the unit may be located.

First check that the differential runs freely, and that the mesh between the differential and the escapement is free. The lost motion between the differential and the escapement should be between .005 and .010 as measured on the pitch line. For instructions on adjusting lost motion see OP 114OA.

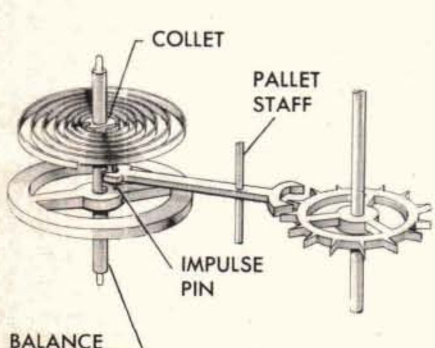
Then check the escapement:

1 Be sure that the escapement does not lock when the cam is rotated past its peak. Also make certain that the cam is smooth.



2 With the balance wheel at rest, the outer turn of the hair spring must remain in the center of the regulator fork when the regulator lever is moved through its full travel.

3 The spacing between the turns of the hair spring must be uniform. Coils must not touch each other when the balance wheel is rotated to its extreme positions. The hair spring at its maximum extension must not touch any part of the assembly other than the inside faces of the regulator fork.



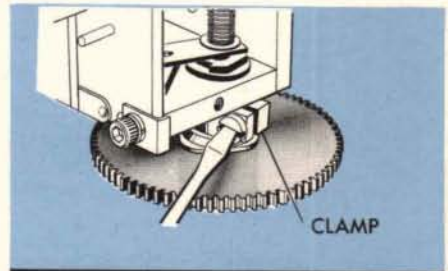
4 The impulse pin must be in a line with the centers of the balance and the pallet staffs when the balance wheel is in free normal position. If necessary to adjust, slip the hair spring collet on the balance staff. Hold the collet and rotate the balance staff until the pin is in line with both staffs. This adjustment should not be attempted by inexperienced personnel.

5 The escapement must be self-starting at all times and must run backward under slight finger pressure on the escapement wheel.

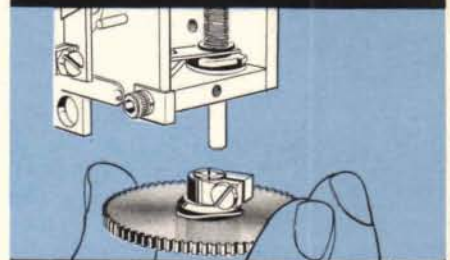
If any of these steps shows the regulator to be out of order, it must be replaced or repaired. If the motor regulator passes these check tests but is still out of time it should be adjusted.

Adjusting the friction relief

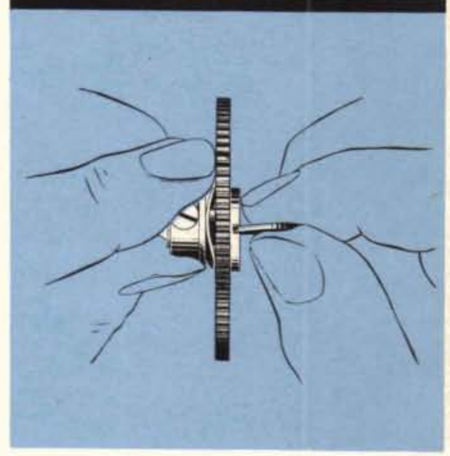
The friction on this gear may be too loose, allowing it to slip on the shaft instead of driving the differential. If it is slipping, it is changing the value of the input to the differential.



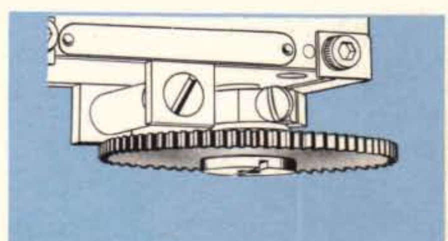
First check the clamp, which may have worked loose. If it is loose, tighten it. If the clamp is all right, but the gear is still slipping, remove the Motor Regulator from the Computer. Then loosen the clamp and remove the gear from the shaft. Use a penny in the slot in the flange on the under side of the gear.



Hold the clamp as shown and hand-tighten the gear with two fingers of each hand. Do not get it too tight, because if the time line of the motor should reverse with the gear too tight, the stop assembly would jam and break.



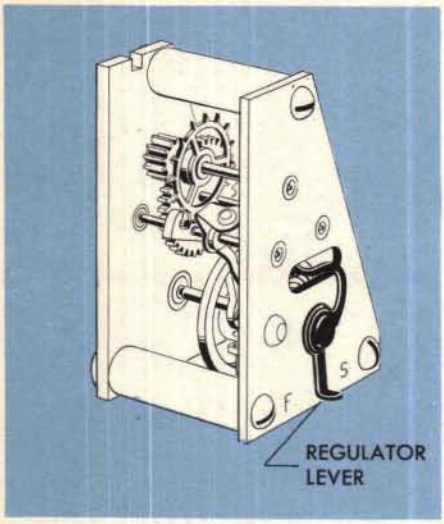
When replacing the gear on the shaft, do not set it too far up. Tighten the clamp and replace the regulator in the computer.



If the input gear has worked up too far on the shaft, it will rub against the edge of the regulator plate. Re-adjust the gear on the shaft by loosening the clamp and lowering the gear. Then tighten the clamp.

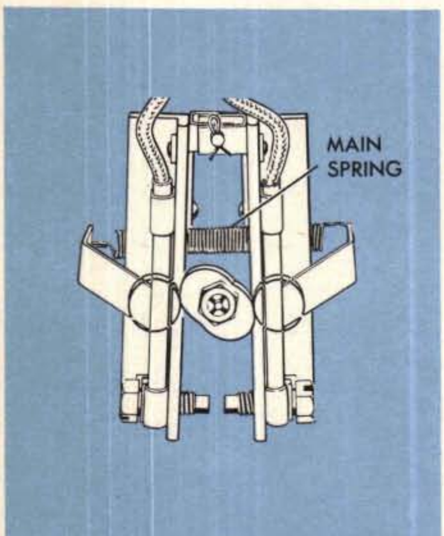
Timing the MOTOR REGULATOR

The Motor Regulator speed should be accurately timed, using a stop-watch to check the time dial driven by the Time Motor. If the timing is out the Motor Regulator can be adjusted. There is a motor regulator test prescribed for each installation, which specifies the timing procedure and the allowable error.



The regulator lever

The regulator lever, an adjustment arm on the clock escapement mechanism, is provided to adjust the escapement's speed. When moved toward *F*, the motor speed is increased. The lever is easily reached by loosening the screw holding the small cover on the front panel. If the lever has been moved to its limit of *F* or *S* and the motor still runs too slow or too fast, then the main spring must be adjusted.



The main spring

Sometimes it is possible to alter the timing slightly by changing the tension of the mainspring.

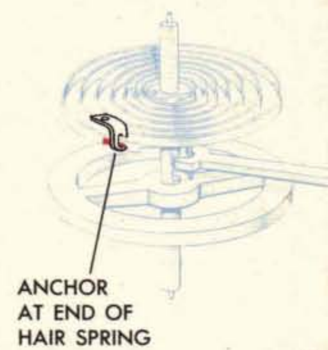
The main spring is located between the contact arms. The arms holding the mainspring should always be tight. If they become loose, the whole contact assembly should be replaced. The mainspring can be stretched in order to slow down the regulator, or shortened to increase the speed. The mainspring may be lengthened or shortened 1/16 inch—*no more*. Some models have an anchor adjustment on the mainspring which is used to shorten or lengthen the mainspring. Where no anchor adjustment is provided, the mainspring may be lengthened. To lengthen: Unhook one end of the mainspring from the arm and stretch it a little at a time. Anchor it again. If the mainspring needs to be shortened, it must be replaced with a shorter one.

If the adjusting lever and the mainspring adjustments fail, replace the escapement. See O P 1140A for instructions.

The hair spring

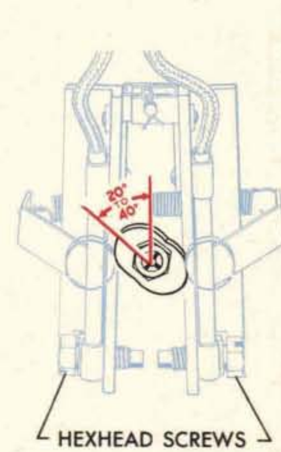
This adjustment should only be made when escapement replacements are not available.

Adjusting the hair spring is a delicate operation and it should be adjusted a little at a time to avoid over-adjustment. *Be very careful not to bend the hair spring.* Lengthening the hair spring will cause the motor to slow down, and shortening the hair spring will cause the motor to speed up. First set the regulator lever in the center between *F* and *S*. Loosen the hair spring from its anchor and lengthen or shorten it as required; then re-clamp it in the anchor. Remember to move the hair spring only a little at a time until the timing is correct. Whenever the hair spring length is changed the collet must be turned on the balance staff to line up the impulse pin and the balance and pallet staffs as described on Page 214. To simplify the hair spring adjustment, the hair spring on later models is held in the anchor by a locking screw.



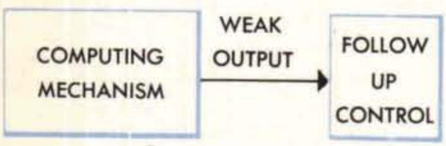
Adjusting the contacts

To adjust the contacts turn both the hexhead screws until the cam has to rotate between 20° and 40° before the contact is broken. This will leave about 1/16 inch clearance between the rollers and the cam when the cam is in its normal position and the regulator is at rest. Some models have no contact adjustment because they have already been properly spaced at the factory.

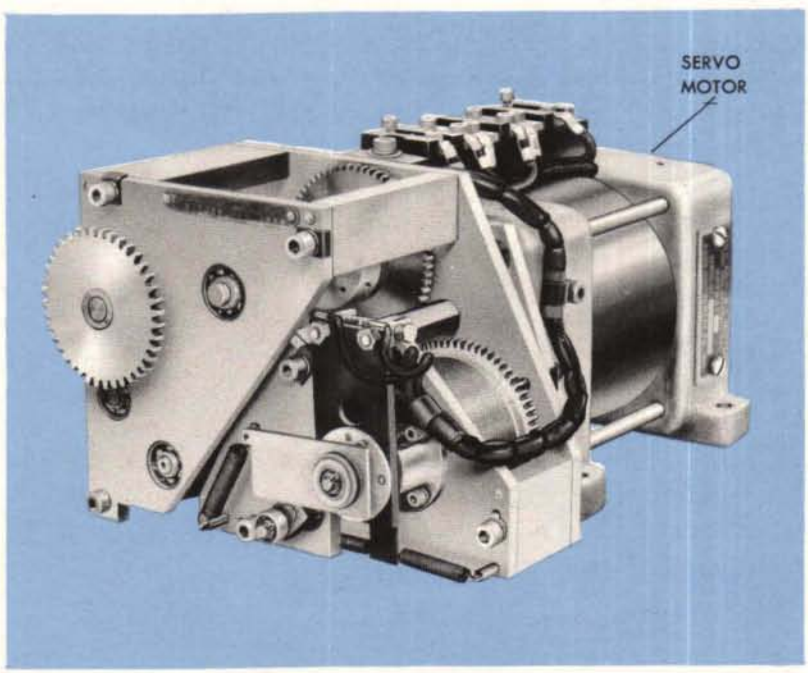


FOLLOW-UP CONTROLS

Computing mechanisms are not designed to drive heavy loads. The outputs from such mechanisms often merely *control the action of servo motors.* The motors do the actual driving of the loads which have to be handled.

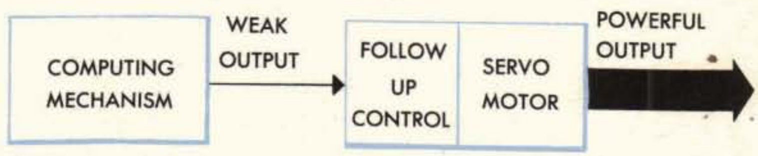


The device which makes it possible for the comparatively weak output from a computing mechanism or any other source to control the action of a servo motor is called a *follow-up control.*

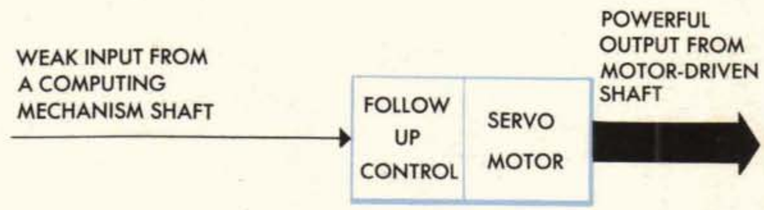


THIS IS A VELOCITY-LAG TYPE OF FOLLOW-UP CONTROL MOUNTED ON A SERVO MOTOR

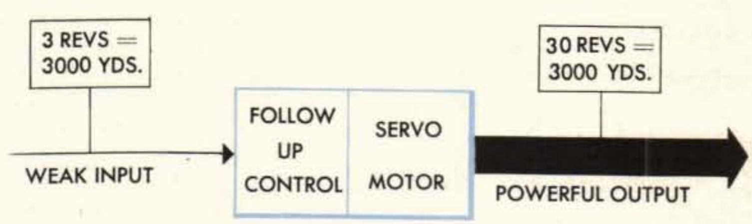
The follow-up control and the servo motor together provide a means of "boosting," or increasing the *weak* output from a computing mechanism into a *powerful* output capable of moving gear trains and shafting rapidly and accurately.



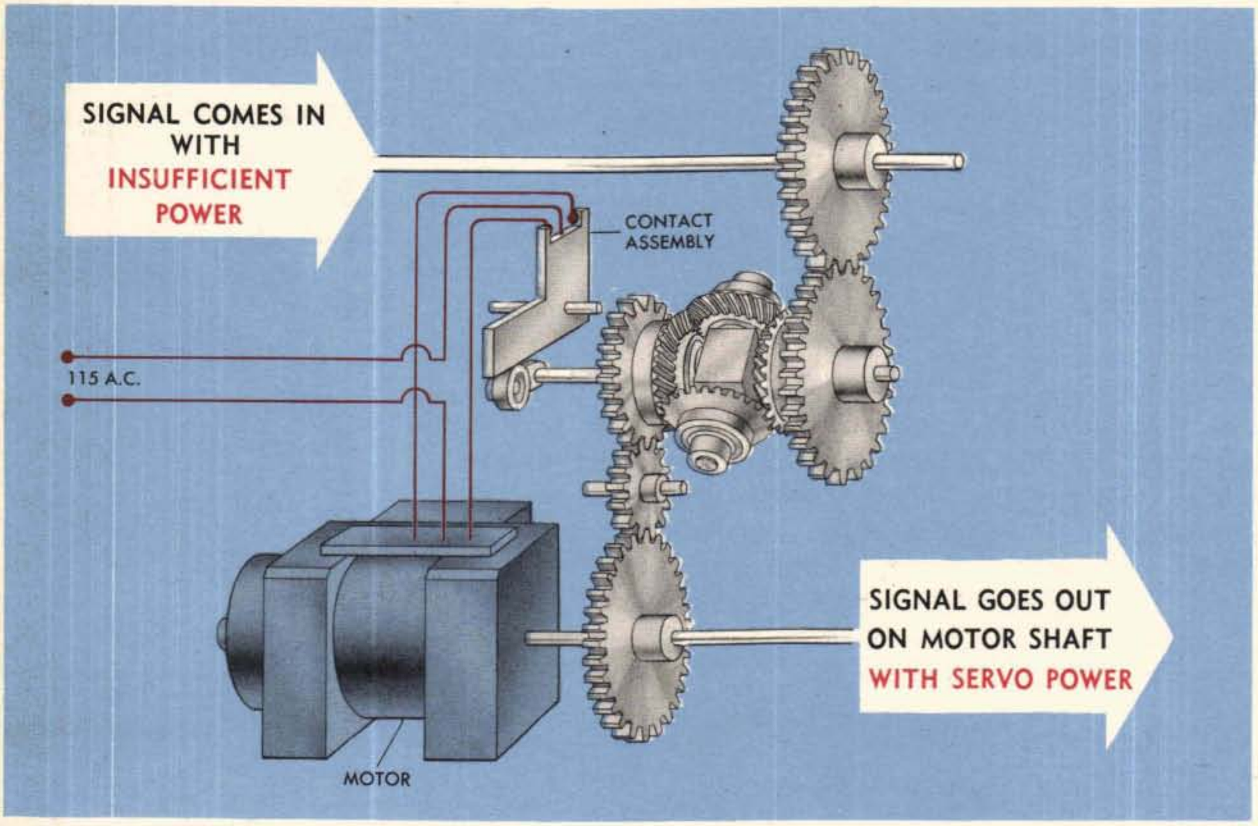
The output from a computing mechanism is considered to be the input to a follow-up control. The hook-up may be pictured this way: The weak output of a computing mechanism is applied as input to a follow-up control. A servo motor drives the output shaft with considerable power.



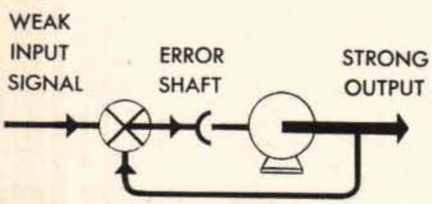
The follow-up control regulates the action of the servo motor in such a way that the position of the output shaft always represents the value of the quantity set into the control by the input shaft. For example, suppose one revolution of the input shaft represents 1000 yards, and one revolution of the output shaft represents 100 yards. Then if the input shaft makes 3 turns (with little power), the output shaft makes 30 turns (with much greater power).



These are the elements



This is a simplified form of follow-up control which will be used to illustrate the general principles of operation of all follow-up controls.



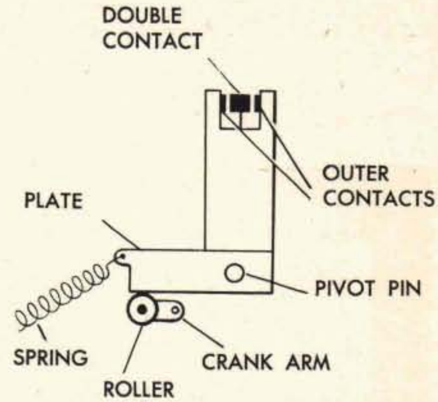
THE ELEMENTS OF A FOLLOW-UP CONTROL ARE OFTEN REPRESENTED SCHEMATICALLY AS SHOWN HERE.

THE DIFFERENTIAL

The differential is used to measure the difference, or "error," in position between the input and the output. The input is geared to one side of the differential. The servo output is used to do two things: (1) to position whatever mechanism is being handled, (2) to drive the other side of the differential. This second operation is known as the servo "response."

When there is a difference between the input and the output, the spider of the differential turns. As this happens, the spider shaft operates a set of contacts which control the action of the servo motor in such a way that the motor drives its side of the differential in the opposite direction to that taken by the input. That is, the servo always drives to reduce the difference, or error, to zero.

# of a FOLLOW-UP CONTROL

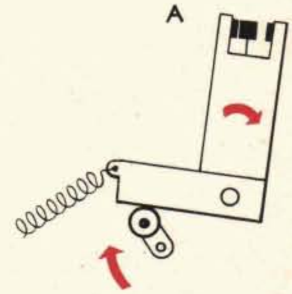


The contact mechanism

The contact mechanism consists of a vertical arm carrying two contacts known as the "outer" contacts. To the base of the arm is fastened a plate projecting to one side. Arm and plate pivot on a pin. Beneath this assembly is a small crank-arm, attached to the differential spider shaft, and at one end of the crank arm is a roller.

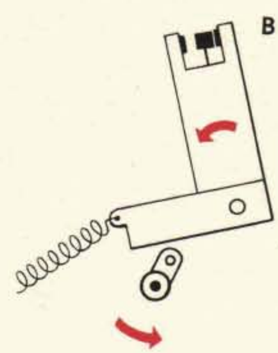
In normal position, the crank-arm is horizontal, and a spring causes the base plate of the contact arm to bear against the roller, holding the contact arm in a vertical position.

Mounted midway between the outer contacts is a center (double) contact.

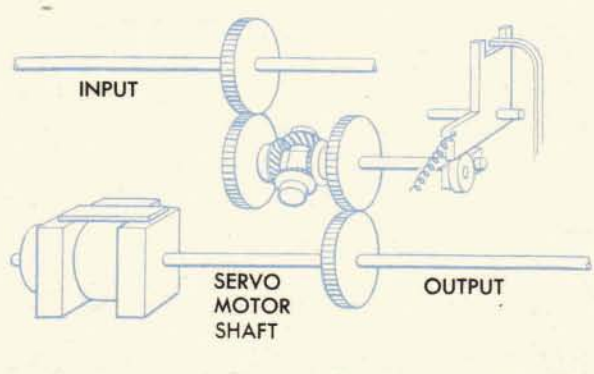


If the crank-arm turns clockwise, it rotates the outer contact arm clockwise (opposing the action of the spring). This brings the outer contact *A* against the center contact.

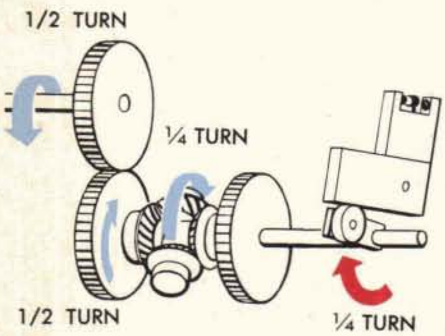
If the crank-arm rotates counterclockwise, the roller ceases to bear against the base of the outer contact arm, and the arm is rotated counterclockwise by action of the spring. This brings the outer contact *B* against the center contact.



When contact is made by *A*, the motor runs in one direction; and when contact is made by *B*, it runs in the opposite direction. In order to simplify the schematic representations which follow, the follow-up control input shaft is geared to the left side of a differential, and the servo motor shaft is geared to the right side of the same differential by a 1:1 gear ratio. Actually this gearing is seldom 1:1.



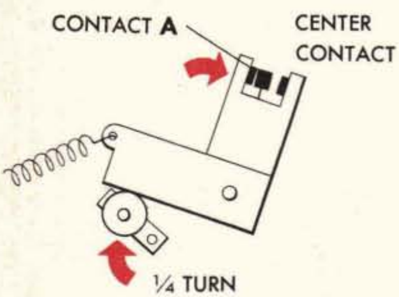
The FOLLOW-UP at work



Suppose the follow-up input turns ½ a revolution. This will drive the left side of the differential ½ turn.

The left side rotates the spider, because the right side of the differential is geared to the servo and held stationary.

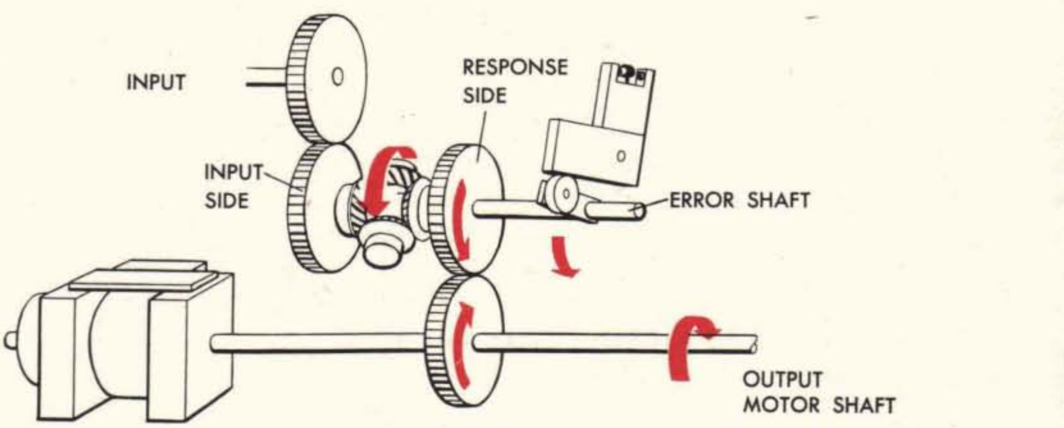
Since the input was ½ turn, the spider turns ¼ turn (in this case clockwise) and rotates the crank-arm ¼ turn (clockwise).



This causes the outer contact arm to be rotated, and the outer contact *A* is brought against the center contact.

Turning on the motor

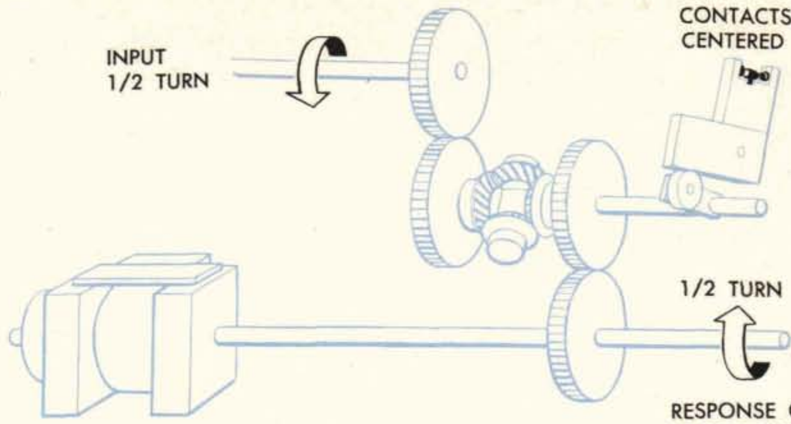
When contact is made, the power supply is connected to the motor in such a way that the motor turns in a direction opposite to that of the input, as shown here:



The motor will run as long as the contacts are closed, and will turn the right side of the differential. This action of the servo is the "response." It causes the spider to be rotated back towards its original position, which in turn causes the crank-arm to be rotated counterclockwise, back towards its original position.

As the crank-arm rotates and reaches its normal position, the spring pulls the outer contact arm back to the vertical position. This opens the contacts and shuts off the power.

THE FOLLOW-UP HAS OBEYED THE SIGNAL. THE OUTPUT IS NOW SYNCHRONIZED WITH THE INPUT



Since the crank-arm is back to its starting point, it has been rotated back ¼ turn. The spider that drives it has therefore also been rotated back ¼ turn.

And since the spider has been driven back ¼ turn, the right (response) side of the differential has been driven back ½ turn. This means that the motor shaft, being geared to the right side by 1 : 1 ratio gearing has also rotated ½ turn—which is *the same amount as the input shaft rotated.*

In this way, the number of revolutions (or fractions of a revolution) of the servo shaft corresponds exactly with the number of revolutions (or fractions of a revolution) of the input shaft from the computing mechanism. So the final position of the motor-driven output shaft corresponds exactly with that of the input from the computing mechanism.

In this way the comparatively weak output from the computing mechanism can be transmitted in powerful form and made to overcome the loads required for operation of other units.

This is the simplest form of follow-up control, and it illustrates the basic principles governing the operation of follow-up controls generally.

The device has been described as if the input had rotated only ½ turn. However, if the input rotates *continuously* it will keep closing the contacts, and the motor will drive continuously to open the contacts, moving the output shaft to keep up with the input.

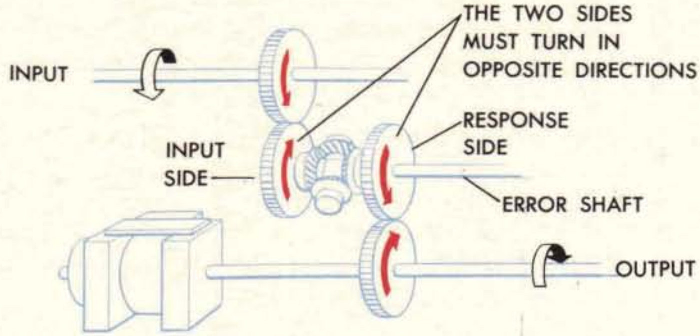
Until the motor has driven sufficiently to make output equal to input, the input side of the differential has, of course, been driven more than the response side. There is a difference or error between input and output values. When both sides of the differential have been driven an equal amount, output synchronizes with input. This is "the point of synchronism," or "point of zero error."

The spider of the differential always measures the error between input and output. Therefore the spider is called the "error shaft." When input and output are synchronized, there is no error, and at this point the spider is back at the position from which it started.

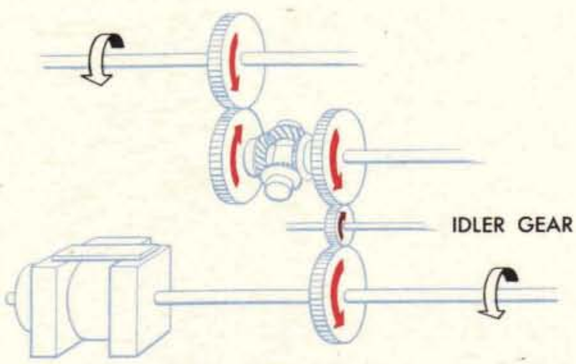
The sides of the differential must turn in OPPOSITE directions

It is not important whether the servo response shaft turns in the same direction as the input shaft or not. The important fact is that the servo response shaft shall be so geared to its side of the differential that *the response will be rotated in the opposite direction to that taken by the input side.*

This means that the servo motor shaft can either be geared to the differential in the manner already shown, which is like this:



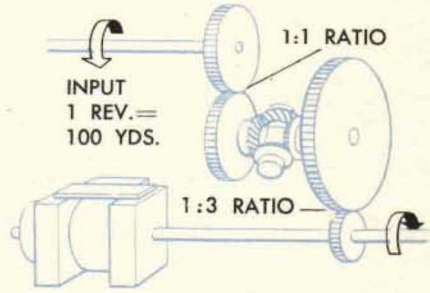
—or, if the output shaft is run in the opposite direction, like this:



Both these methods cause the response side of the differential to rotate in the opposite direction to the input side.

Other gear ratios can be used

For the sake of simplicity, gearing has been shown as 1:1 ratio throughout. This is not usually the case.



OUTPUT 3 REVS.=100 YDS.

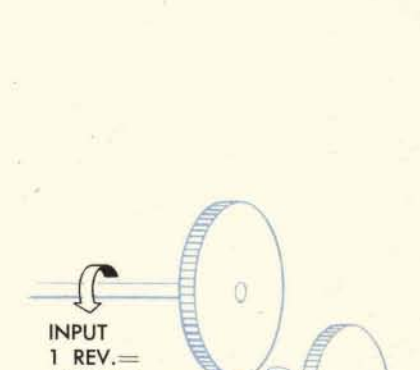
As long as the positions taken by the output shaft represent the values of the quantities set into the control by the input shaft, the gear ratios in the line can vary.

If, for example, 3 revolutions of the output shaft represent 100 yards, and only one revolution of the input shaft represents 100 yards, proper gear ratios will provide for rotating the output shaft 3 times for each revolution made by the input shaft.

If a greater reduction is needed, there may be gear ratios on both the input and output sides of the differential.

Whatever the ratios the follow-up will synchronize when the TWO SIDES OF THE DIFFERENTIAL have turned equal amounts.

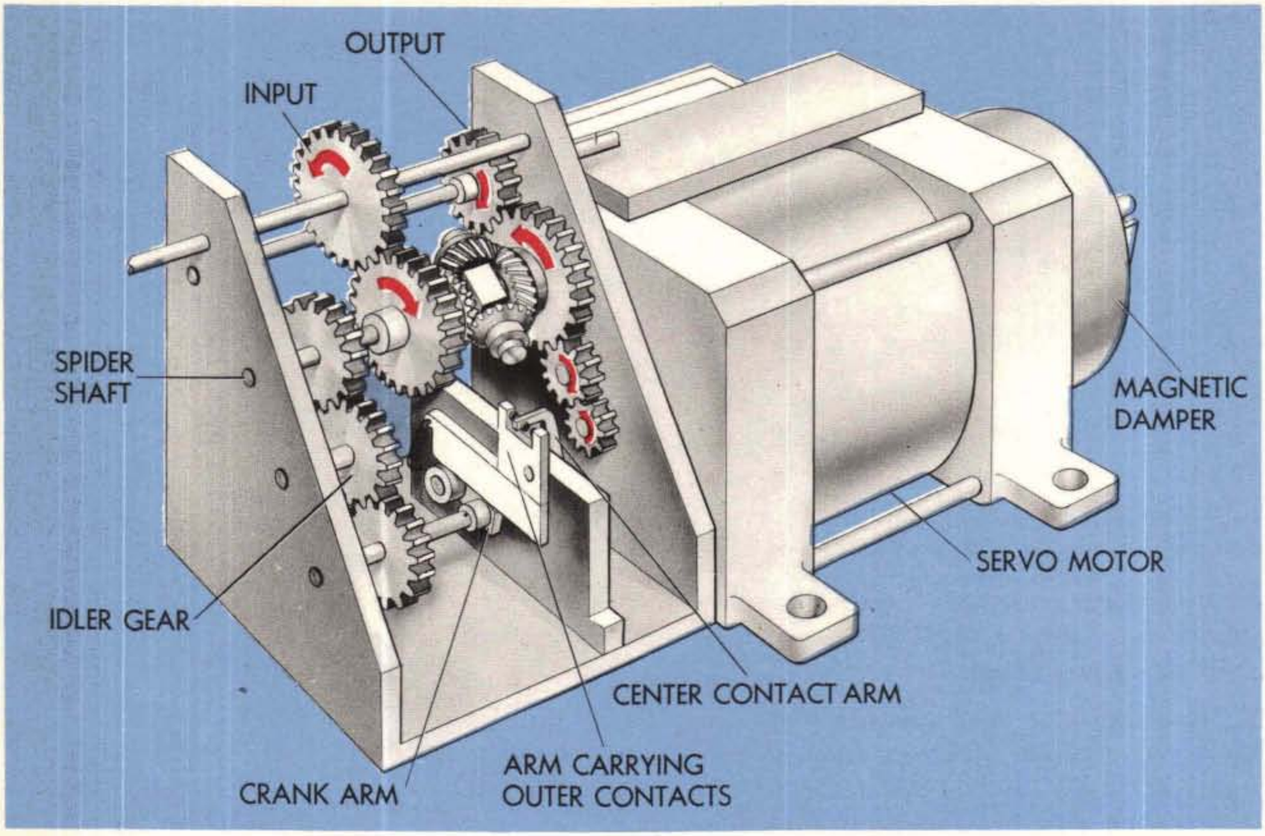
Here, for example, 1 revolution of the input shaft and 12 revolutions of the servo output shaft both represent 100 yards. The input shaft turns one side of the differential through 4:1 ratio gearing. The servo output shaft turns the other side of the differential through 1:3 gearing.



OUTPUT 12 REVS.=100 YDS.

Assume that the input shaft turns 1 revolution. It will turn its side of the differential 4 revolutions. The servo output must now drive until it turns the other side of the differential 4 revolutions. Since the servo shaft in this example must turn 3 revolutions in order to turn its side of the differential 1 revolution, it must turn a total of 12 revolutions to turn the differential 4 revolutions.

So each revolution of the input will cause the servo output to drive exactly 12 revolutions. The 12 revolutions of the motor output shaft represent the same 100 yards which are represented by 1 revolution of the input shaft.

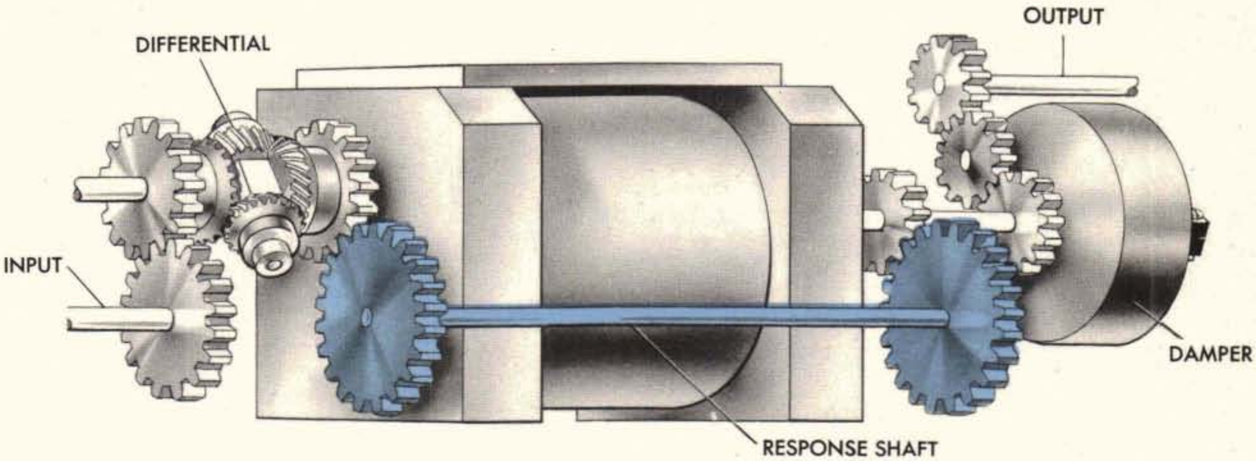


Here is a follow-up ASSEMBLED

The elements of a follow-up control are mounted so that the device will take up as little space as possible and may be installed rapidly at any point in the computer.

The elements are often assembled as shown above. This is not an actual follow-up assembly. The gearing has been spread out for the sake of clarity. In this arrangement, the crank-arm controlling the contacts is driven by the spider of the differential through an idler gear.

Other elements are easily added to this form of assembly, permitting the most complete type of follow-up control to remain a compact unit.



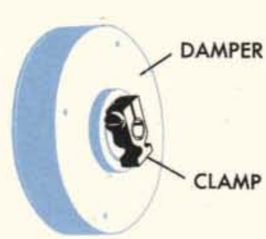
Output and input may be at OPPOSITE ENDS of the servo

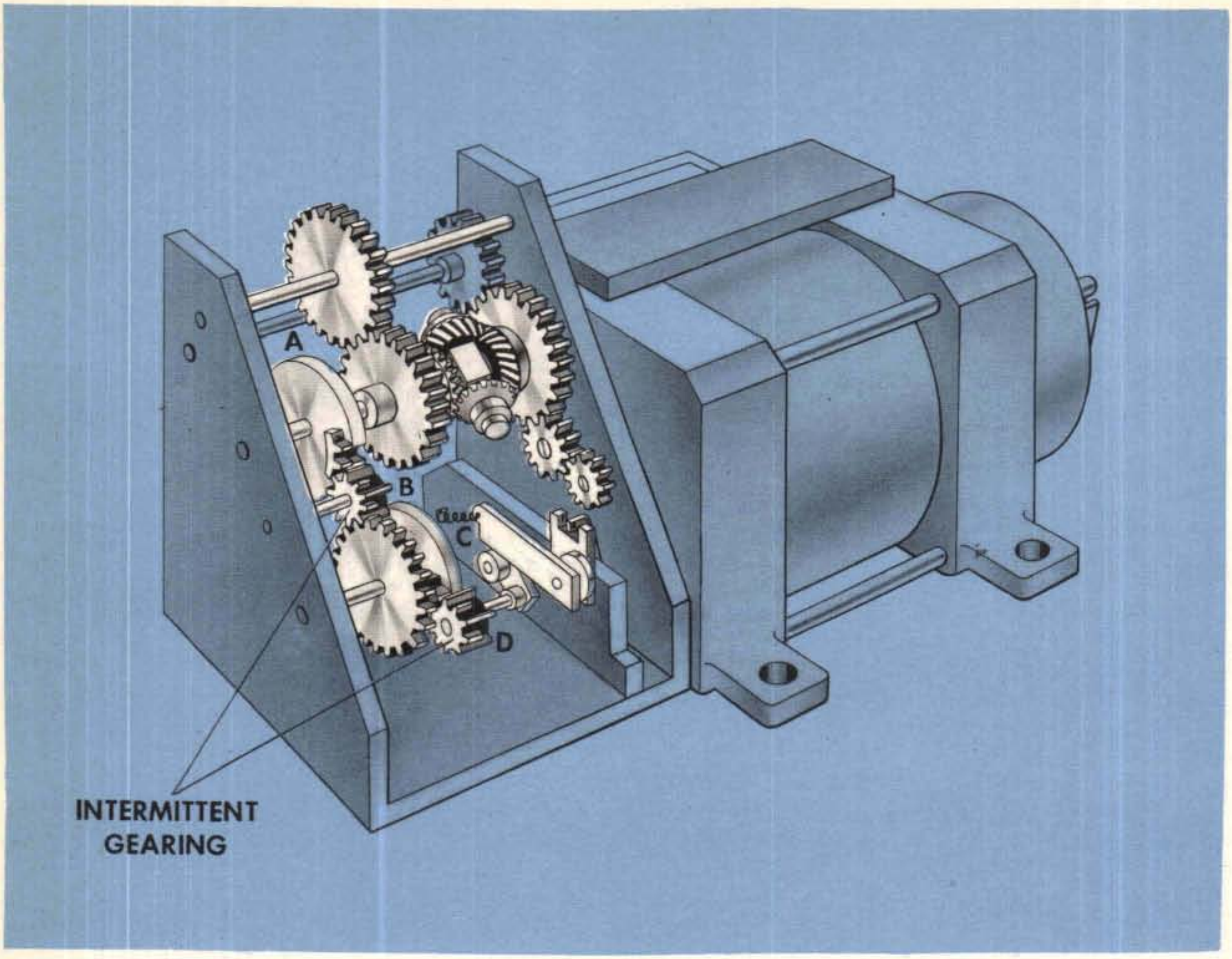
Usually the differential and the output drive shaft are at the same end of the servo motor. In some assemblies the drive is taken from the other end of the motor and transmitted to the differential and contact assembly by a long shaft.

However the parts of a follow-up are arranged, the principles of operation are always the same.

Sometimes a magnetic damper is used

After the servo has synchronized on a fixed signal, it tends to oscillate a little back and forth across the point of synchronism. When a damper is placed on the rotor shaft, it reduces the oscillations by resisting sudden starts or reversals of direction of the rotor. The chapter on the Magnetic Damper, page 334, describes damper action in detail.





The INTERMITTENT GEARING

The majority of follow-up controls employ "intermittent" gearing. This type of gearing permits the input shaft to make many revolutions in relation to the shaft which carries the crank-arm.

This gearing has two purposes:

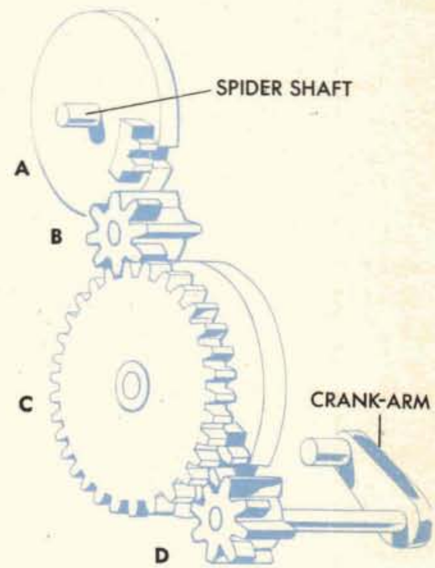
1 An input may come into a follow-up control faster than the servo can convert it into an output. When this happens, the extra input is "stored" in the intermittent gearing until the servo output can catch up.

2 When a servo is shut off, the input is stored in the intermittent gearing until the servo motor is energized.

This gearing is so constructed that while the input is driving continually, the output from the intermittent gearing drives a fixed small amount and then remains stationary. The input must turn a certain amount before the output moves again.

The intermittent gearing used in follow-ups is not to be confused with the gearing of the Intermittent Drive.

Intermittent gearing works like this



Gear *A* is a "sector gear," having only two teeth.

Gear *B* has 8 teeth, every other tooth being partly cut away. This type of gear is called a mutilated pinion.

If gear *A* starts from the position shown and turns one revolution, it will turn gear *B* only two teeth, or ¼ of a revolution.

Gear *B*, therefore, turns once for every 4 revolutions of the spider shaft.

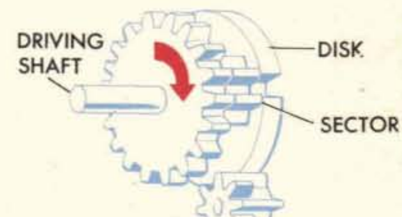
Gear *C* has 40 teeth. This gear turns once for every 5 revolutions of the small 8-tooth gear, *B*, or once for every 20 revolutions of the spider shaft.

Gear *C* has a 2-tooth "sector" gear which meshes with a second 8-tooth gear *D*. One revolution of *C* turns gear *D* ¼ turn.

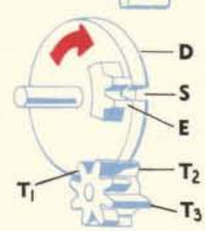
But *D* is fixed to the shaft which rotates the crank-arm, so that one revolution of *C* rotates the crank-arm ¼ turn.

In this way rotating the input a small fraction of a revolution, with both sectors meshing, will move the crank-arm ¼ turn. The crank-arm will then remain at this new position for 20 revolutions of the spider shaft or 40 revolutions of the input shaft. After 40 revolutions of the input shaft both sectors will again be in mesh at the same time and the crank-arm will again rotate ¼ turn.

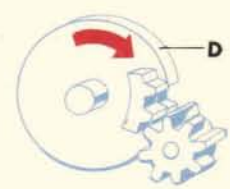
A close-up of the action



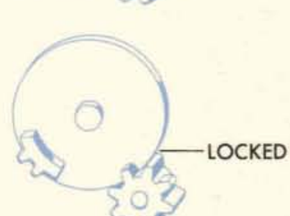
The "sectors" are mounted on disks. Sometimes the disks are joined to the gears which drive their shafts. Sometimes the disks are separate from their driving gears. In either case the action of the "sectors" is the same.



When the disk is rotated, the lower edge of tooth *E* comes against the small tooth T_1 on the small gear, and forces the small gear around ⅛ revolution.

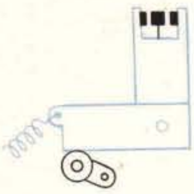


As the disk continues rotating the long tooth T_2 enters slot *S* in the disk. The second sector tooth forces the small gear to rotate an additional ⅛ revolution.

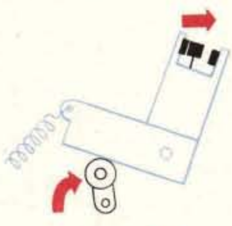


After the ¼ turn of the small gear, the smooth edge of the disk *D* rides against the long teeth T_2 *and* T_3, keeping them "locked" in one position. Because of this locking effect, there can be no further movement of the small gear until the two teeth of the sector gear travel through one complete revolution.

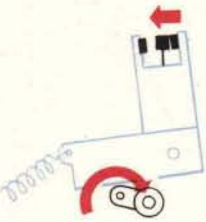
Why intermittent gearing

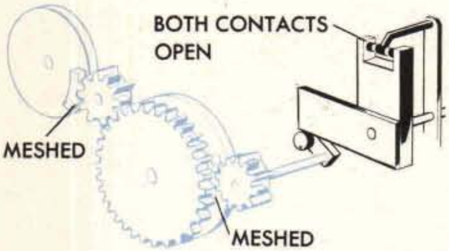


CORRECT CONTACTS CLOSED FOR CLOCKWISE MOTION OF CRANK-ARM



WRONG CONTACTS CLOSED FOR CLOCKWISE MOTION OF CRANK ARM





ZERO POSITION

Sometimes an input goes into a follow-up control WHEN THE SERVO MOTOR POWER IS SHUT OFF. This results in only one side of the differential being rotated, no response action on the part of the motor being possible.

Without intermittent gearing the crank-arm can be rotated through 360° by a comparatively small input and will turn the crank-arm past the place where the correct contacts are made to touch, and bring it around so that the contacts come together on the opposite side. This will throw the mechanism out of synchronism, since the motor will drive in the wrong direction when the power is turned on.

With intermittent gearing this result can be avoided.

When the crank-arm is in zero position (contacts open) the sector gears are in mesh with the 8-tooth gears as shown. The slightest input causes the spider shaft to turn and rotate the crank-arm a little in either direction, bringing an outer contact against a center contact.

Thus for small signals the contacts move as if the crank-arm were directly driven. Because of this, the follow-up contacts move quickly, giving quick response.

On the other hand, if a signal continues to come in, the disk portion of the intermittent gearing holds the crank-arm stationary with the contacts correctly positioned until the second sector gear has made a complete revolution. This means that the input will turn a considerable number of revolutions before the contacts will be moved again.

The intermittent gearing, therefore, acts like reduction gearing after it has positioned the contacts, and gives the advantage of a large reduction ratio between the differential and the crank-arm.

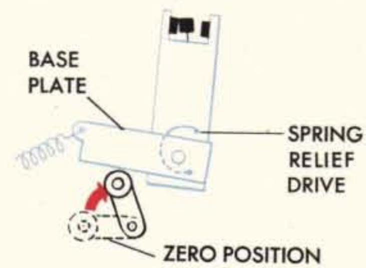
But during the time that the two sector gears are in mesh with the two 8-tooth gears the intermittent gearing is a sensitive direct drive.

is used . . .

In normal operation the motor is energized, and immediately drives its (response) side of the differential at the same time as the input drives. Both input and output move practically simultaneously and the mechanism does not normally get out of synchronism.

When the motor power is shut off, a small manual input will cause the crank-arm to rotate $\frac{1}{8}$ turn and close the correct contacts. But the intermittent gearing allows the spider shaft to turn 20 revolutions more before the crank-arm will move again. So it is possible to feed a considerable amount of input into the control and still have the correct contacts remain closed.

When the power is again turned on, the motor will immediately drive in the right direction. The response will rotate the spider back towards zero position, resulting in a correct output corresponding to the input.



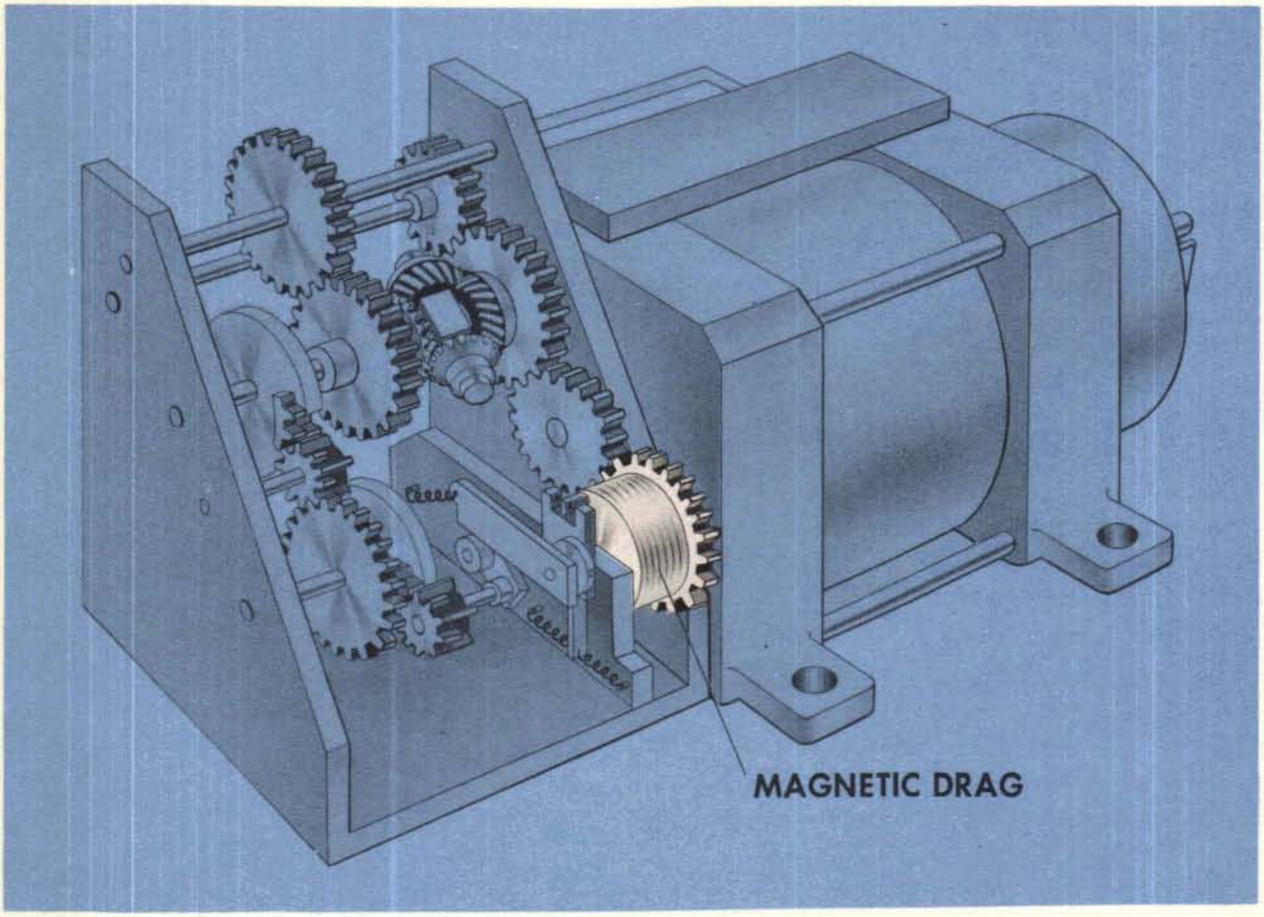
In practice, the range of possible input is increased by using a spring relief drive between the base plate and the outer contacts. This spring drive allows the crank-arm to turn to two positions while the contacts remain closed on the same side.

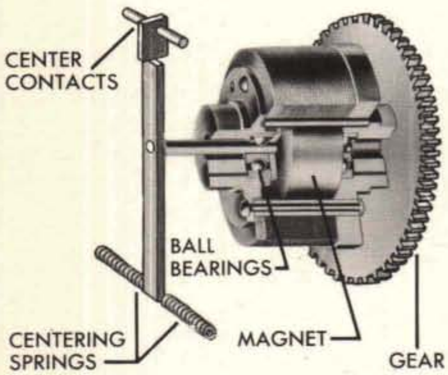
With the same gearing, the spider shaft can now be rotated 40 times, yet the correct contacts will remain closed.

In this manner, synchronism between input and output is maintained throughout a large range of input values.

Any input value coming into a follow-up control when the servo power is off is, in effect, "stored up" in the intermittent gearing until the servo is again energized.

The MAGNETIC DRAG





Up to this point, for the sake of simplicity, the center contact arm has been indicated as fixed to the frame and stationary. In practice, however, the center contact arm is mounted on a shaft which can be rotated, within limits, by a "Magnetic Drag."

This drag consists of an outside frame and an inner magnetized core, to which is fixed the shaft carrying the center contact arm.

The drag is assembled into the follow-up control as indicated above, and the outside frame is geared to the motor rotor shaft

When the servo drives, the outside frame of the drag is rotated. This causes the inner core to be rotated to a certain degree, and the center contact arm is rotated to the same degree, against the pull of the centering springs.

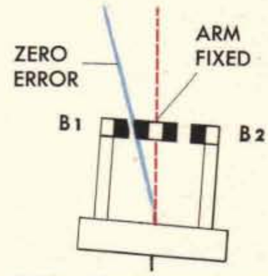
When the motor stops driving, the frame of the drag stops rotating, and the center contact arm is returned to zero position by the centering springs.

Its job in the follow-up

When a signal of a given value goes to a follow-up control, the motor drives until the output equals that value. In doing this, the motor is said to "synchronize to a fixed signal" since the value of the signal remains unchanged.

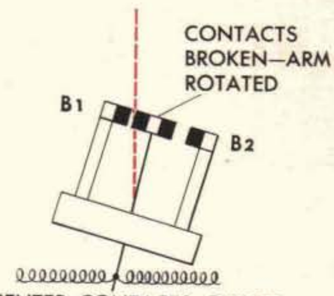
The servo motor, however, is unable to stop suddenly at the point of synchronism, because of the momentum developed by its comparatively heavy rotor and the mechanism which it is driving, which keeps the rotor turning after the power is shut off. The power to the motor must, therefore, be shut off BEFORE the motor reaches the point of synchronism.

The magnetic drag enables this to be done by offsetting the center contact arm, through which current is being supplied, in such a way that the servo response rotates the outer contact away from the center contact before the point of synchronism is reached.



FIXED CENTER CONTACTS. CONTACTS BREAK AT BLUE LINE—POINT OF ZERO ERROR

As this outer contact is rotated away, the *opposite* outer contact is brought up to the center contact. This causes the current in the motor coils to reverse. Reversal of current in the motor coils applies a torque to the servo rotor which tends to prevent the rotor turning in its original direction. Such a torque acts as a brake, rapidly slowing the rotor down, and eventually causing it to reverse its direction of rotation.



CENTER CONTACTS OFFSET. CONTACTS BREAK AT RED LINE—BEFORE THE POINT OF ZERO ERROR

As the rotor reverses, the drag offsets the center contact arm in the opposite direction, and the same process is repeated. Each time the contacts are offset in this manner and torque is applied to the rotor, the speed of the servo is decreased. Action of the magnetic drag, therefore, tends to bring the motor quickly to a standstill.

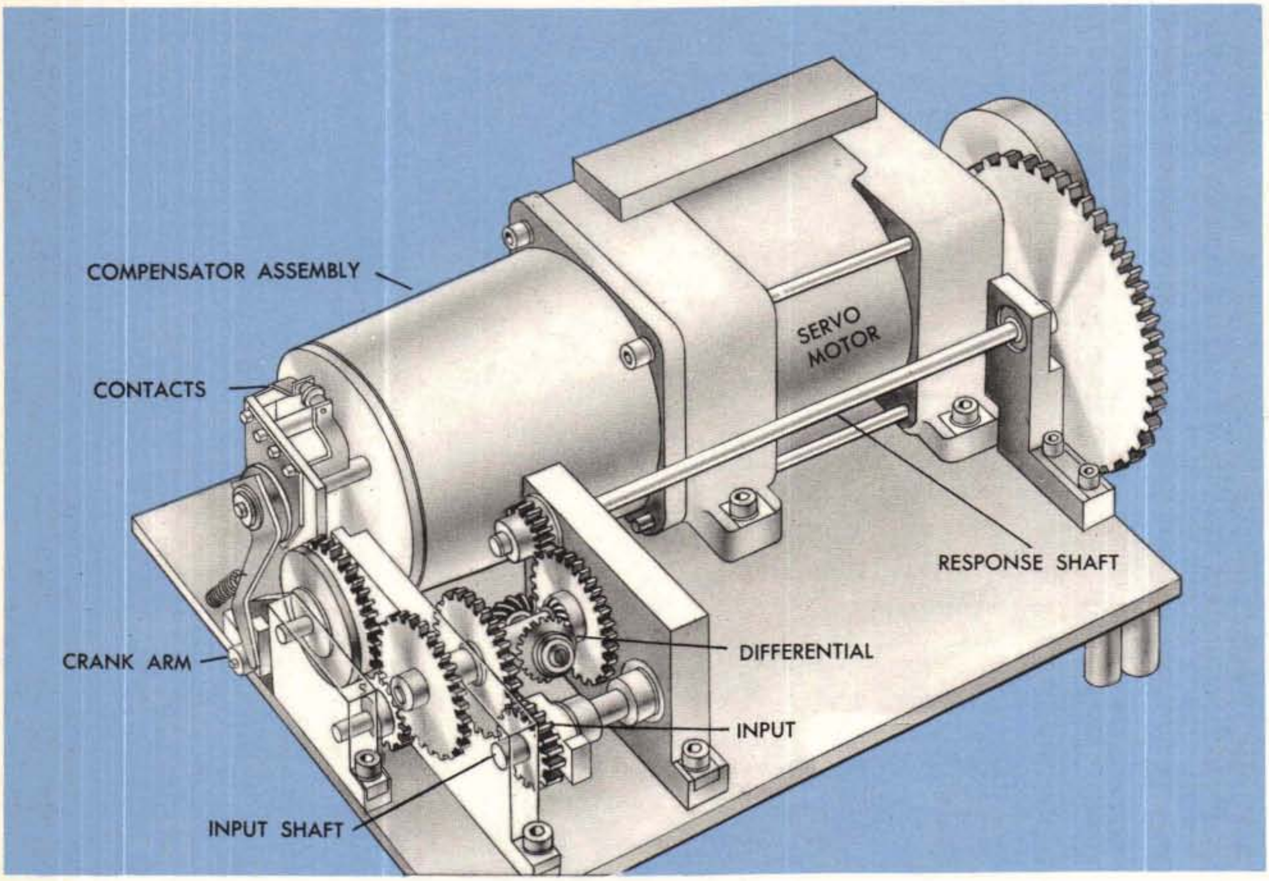
After the motor has been brought to rest at the point of synchronism, and the output, or powered shafting, is positioned exactly in accordance with the fixed value of the input, the drag may come into action in this way:

The load on the powered shafting often causes the servo motor to "drift off" its true position. When this happens the servo response acts through the differential to swing the outer contact arm over in such a way that the motor drives the powered shafting back to its correct position.

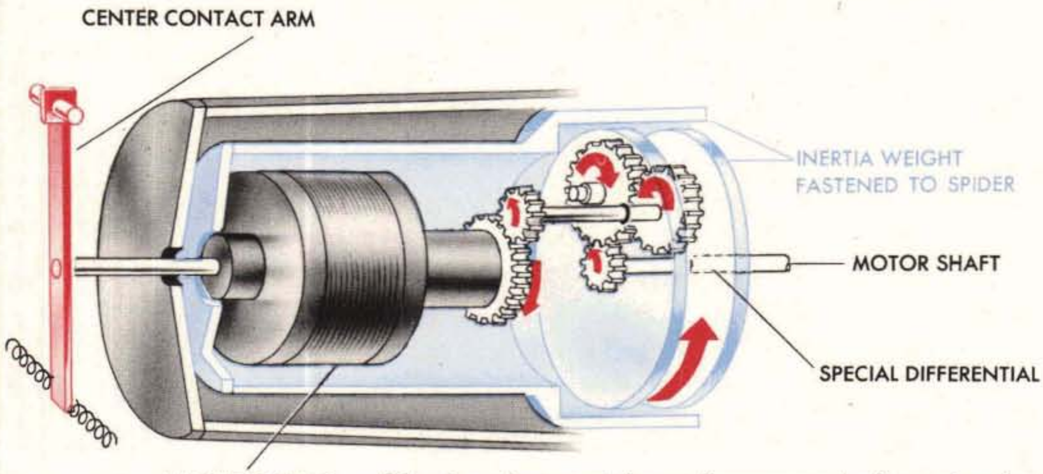
In doing this, the motor again tends to overrun the point of synchronism, and were it not for the action of the drag, a series of oscillations would occur resulting in the servo rotor and the powered shafting swinging back and forth by an amount proportional to the space between the contacts.

Operation of the drag is described in detail in the supplement section titled "Magnetic Drag," page 324.

The COMPENSATED follow-up control



This type of follow-up control is easily recognized by the round grey housing attached to the servo motor.



The housing contains a "compensator" mechanism consisting of a magnetic drag and special type differential equipped with an inertia weight. The operation of the compensator is described in detail on Page 338.

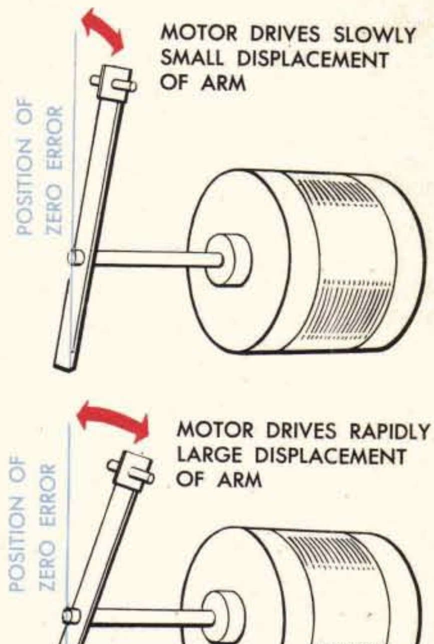
Purpose of the compensator mechanism

It has been shown that the magnetic drag helps to bring the servo motor to rest at the point of synchronism by offsetting the center contact arm.

In doing this job, however, the drag gives the follow-up certain characteristics which cannot be allowed in some applications.

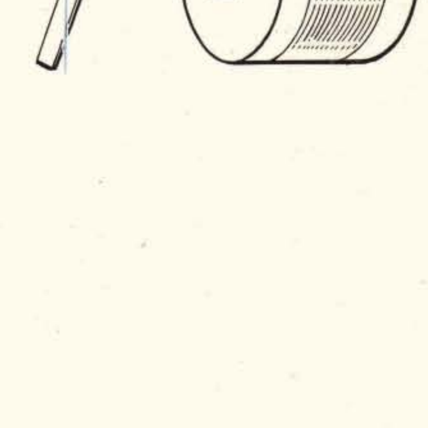
The drag offsets the center contact arm by an amount which is proportional to the speed at which the motor drives. This does not introduce an error as long as the signal is a fixed signal, for the powered shafting is merely positioned in accordance with the value of the fixed input. But when the follow-up has to follow a signal which keeps changing at a constant speed, conditions change. In following such a signal, the motor has to drive at a constant speed to keep the output matched with the input.

As the rotor of the servo turns, it tends to build up speed, and drive too fast. When this happens, the contacts open, for it means that the motor drives past the point of synchronism. When the contacts open, the motor loses speed and the contacts close again. Throughout this operation an outer contact and the center contact make and break the circuit, and the frequent breaking of the circuit prevents the motor from driving too fast.



When a drag is built into a follow-up, the center contact arm is offset and the contacts do not open on the point of zero error. When the contacts do open, the output (or powered shafting) is not on the correct value, although it is moving at the correct speed. The output value will not read exactly the same as the input value at any given instant.

This error can be ignored in some cases but not in all. To eliminate this error the compensator mechanism is included in the follow-up control, and a unit which has such a mechanism is known as a "compensated follow-up."



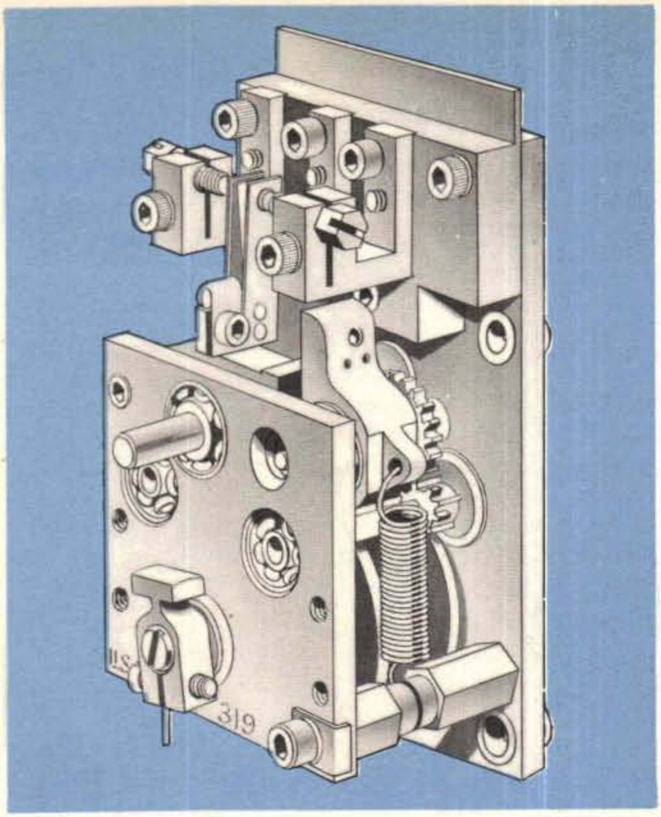
Operation of the compensated type control

The compensated follow-up is just like the velocity lag type, except that it has a spur gear differential and inertia weight built into it.

For small, quick changes of input, the inertia weight does not move, and the drag acts on the contacts as if only a drag were used. Thus small oscillations are eliminated by the drag.

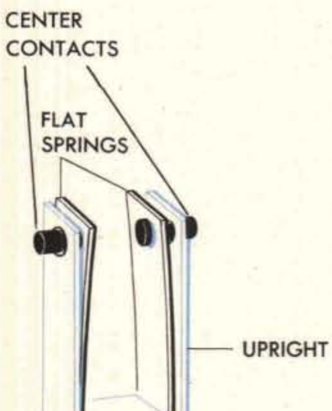
When a signal continues to change at constant speed, however, the inertia weight starts to turn, and gradually picks up speed.

As this happens, the frame of the drag slows down, so that the offset of the center contact arm is reduced gradually to zero—and the arm is returned to its normal position at zero error by the centering springs. This means that there can be no error, or difference, between input and output even though the signal is changing at a constant speed.



The OSCILLATING follow-up control

This type of follow-up is found only in the older types of instruments. It is designed to reduce oscillations of the motor shaft just as the drag and compensator do in the later designs. It consists of a mechanism that causes the center contact to jiggle back and forth between the outer contacts so that contact is made on one side and then on the other very rapidly. When synchronized to a fixed signal the motor gets a "kick" first in one direction and then in the other. These kicks come so fast that the motor shaft only jiggles a little and may be considered stationary. When a change in signal comes into the input, the contacts shift so that the moving center contact makes on one side only and the motor drives in the proper direction. A study of the construction of the parts will make it easier to see just how this works.

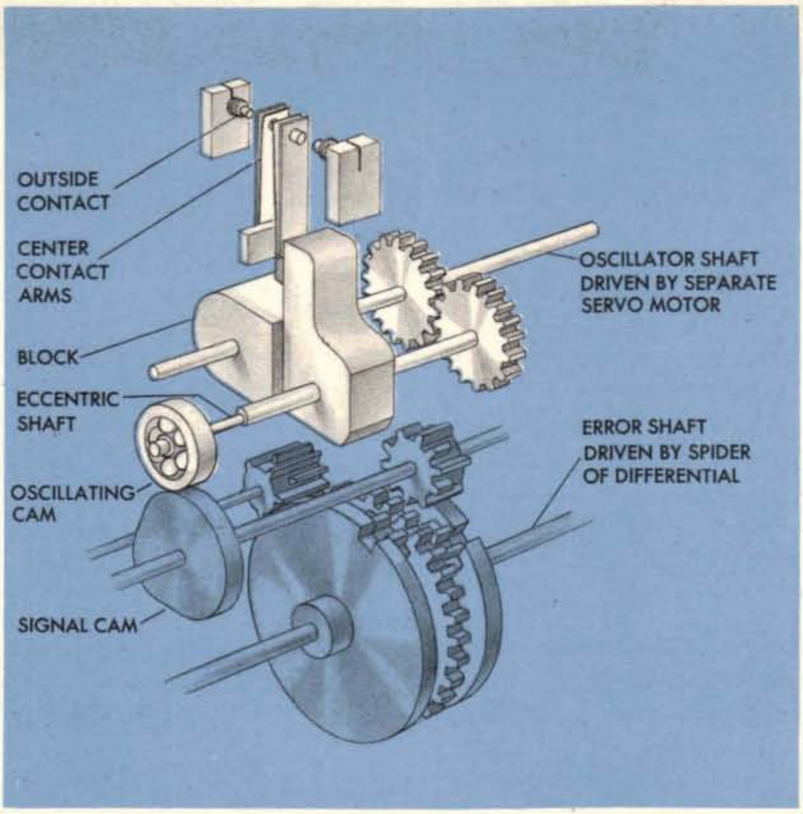


The contact assembly

The outer contacts on this control are stationary, and the center contacts are rotated against them (the reverse procedure to that used by the other type of follow-up controls already described).

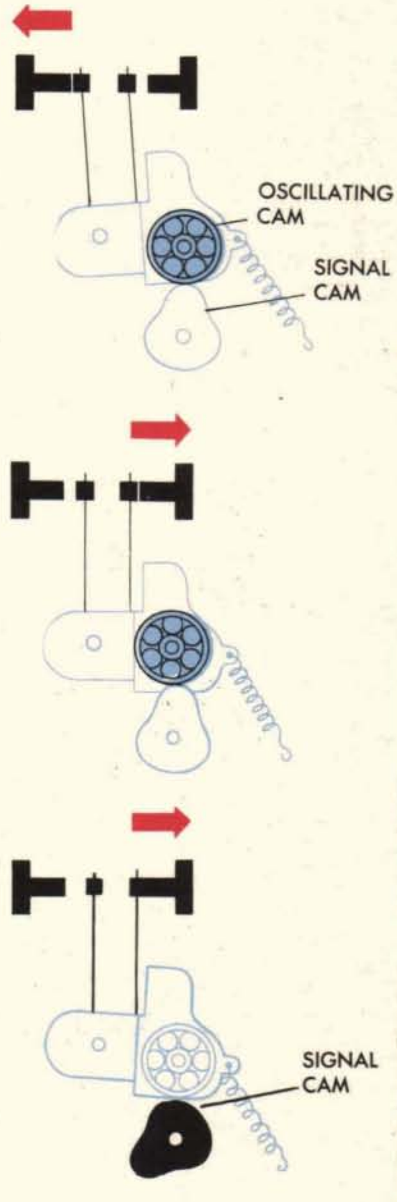
Each center contact is mounted on its individual contact arm, which consists of a stiff upright portion and a flat spring—as shown here. The stiff uprights accurately position the contacts which are mounted on the springs. The springs normally press against the uprights.

The center contact assembly is mounted on a block, and this block may be moved by two cams. an oscillating cam, and a signal cam.



NOTE:

In these diagrams, the shape of the signal cam has been altered to simplify the description of its operation.



The oscillating cam

The oscillating cam is driven around continuously, at constant speed, by a servo motor used especially for this purpose. As it revolves, the cam rocks the center contact assembly block and causes the center contact arms to move a few degrees from side to side. At the point of zero error, when the center contact arms are standing vertical, midway between the outer contacts, the oscillating cam, by rocking the block, can cause the center contacts to tilt over first towards one outer contact and then towards the other. The center contacts are tilted over or "oscillated," *sufficiently to touch one outer contact lightly and then the other in rapid succession.*

The signal cam

Riding against the oscillating cam is the signal cam. This cam is fixed to a shaft which is driven, through intermittent gearing, by the spider of a differential geared to the follow-up servo motor.

Any movement of the differential spider, therefore, causes the signal cam to rotate, and rotation of this cam results in the center contact assembly block being pushed over to one side or the other depending upon the direction of the signal.

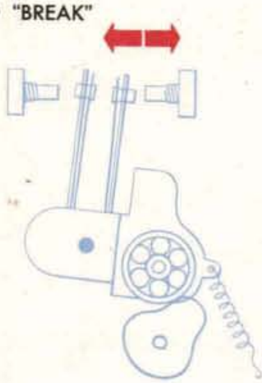
This displaces the center contact arms from their normal, vertical position by a considerable amount, and brings one center contact or the other firmly against an outer contact.

How the OSCILLATING follow-up

It has been shown that the center contacts are moved in two distinctly different ways: (1) they are constantly jiggling back and forth—or vibrating, and (2) they are swung over, when the block on which they are mounted is tilted by the signal cam, against one outer contact or the other.

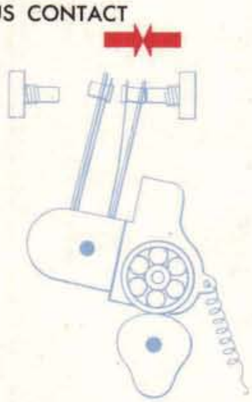
The oscillating cam revolves and causes the center contact arms to oscillate. An incoming signal causes the signal cam to turn and move the center contact assembly toward one outer contact.

SLOWLY CHANGING SIGNAL
"MAKE" AND "BREAK"



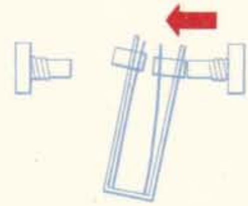
For a fixed signal the center contacts hit both outer contacts equally in rapid succession and the motor shaft merely oscillates a small amount. When the signal value changes slowly, the center contact hits one outer contact longer than the other and the motor, getting a stronger kick in one direction than the other, drives slowly in that direction. For a rapidly changing signal, the center contact continually touches one outer contact and the motor drives continually to follow the signal. In this case the center contact assembly has moved over far enough so that the one contact is held firmly against an outer contact while the spring on which the contact is mounted absorbs the movement caused by the oscillating cam. Consequently there is no "make and break" action and the power supply to the motor is continuous. The motor is continually energized until it builds up speed to follow a rapidly changing signal.

RAPIDLY CHANGING SIGNAL
CONTINUOUS CONTACT

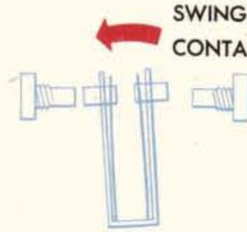


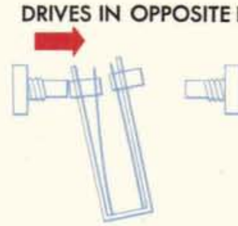
works . . .

The motor always drives the center contact arms back to their normal position, midway between the outer contacts.



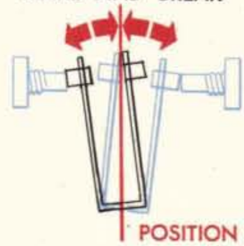
As the motor approaches the point of synchronism, the center contact is no longer held firmly against the outer contact. Instead, it begins to hit the outer contact intermittently and as the error reaches a small value, the center contact begins to hit the opposite outer contact intermittently. The motor then receives a series of "kicks" which tend to stop it before it reaches the point of synchronism.

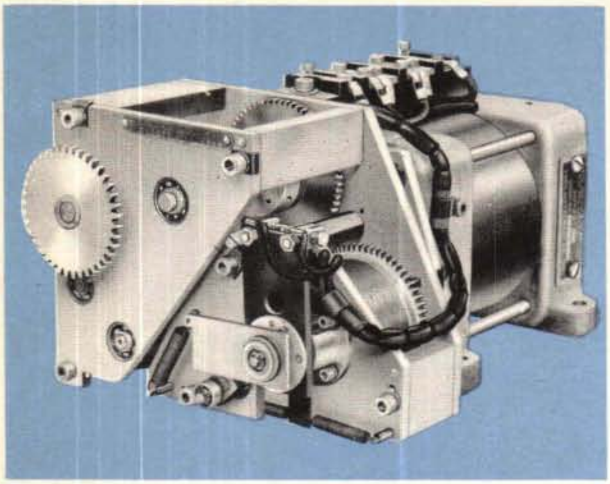




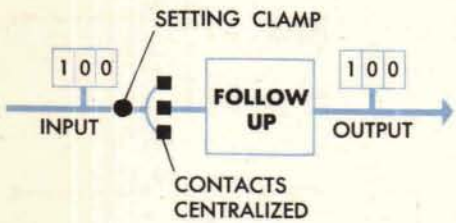
For a fixed signal the arms are centered and the oscillations of the center contact are then sufficient to bridge the gaps between the center and outer contacts, and the servo power supply circuit is closed and broken equally, first on one side and then on the other, in rapid succession. The motor, therefore, is given no chance to build up speed in either direction. Every slight "kick" it receives from the current on one side, is almost immediately neutralized by an equal "kick" from the other side.

The rotor movement becomes so small that it is negligible, and the motor may be considered as standing stationary on the position of zero error.





SYNCHRONIZING

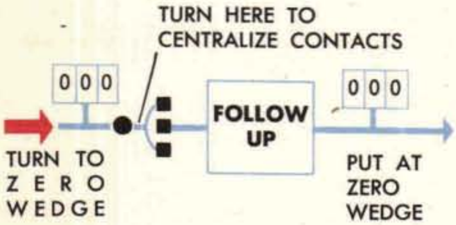


The Follow-up is an electromechanical booster that steps up the available mechanical torque for positioning gearing and mechanisms.

The only relationship to be set is the one between the input and the output. For any given setting of the input counter, the contacts should be *centralized* when the output counter agrees with the input counter.

To set the contacts

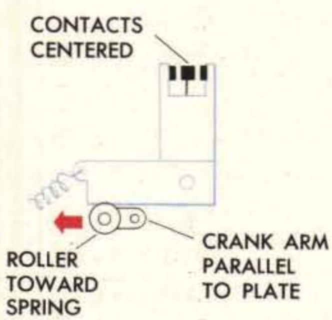
1 Turn the input until the input counter is at zero. Wedge the input.



2 Put the output counter on zero. Wedge it.

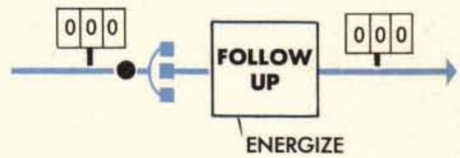
3 Centralize the contacts by slipping through the setting clamp. This is called "synchronizing the follow-up." Most follow-ups are synchronized when the following conditions have been satisfied:

a Contacts centered
b Roller toward spring
c Crank-arm parallel to plate



4 Slip-tighten the setting clamp. Remove the output wedge.

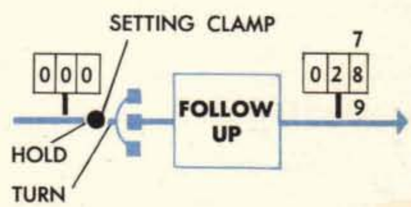
the FOLLOW-UP



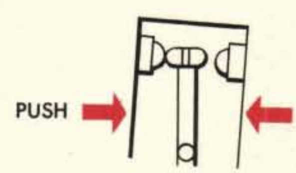
5 Energize the follow-up. The output counter should remain in agreement with the input counter, if the contacts are correctly set.

Here these counters are in agreement.

6 Here the counters do not agree, because the contact setting was incorrect.



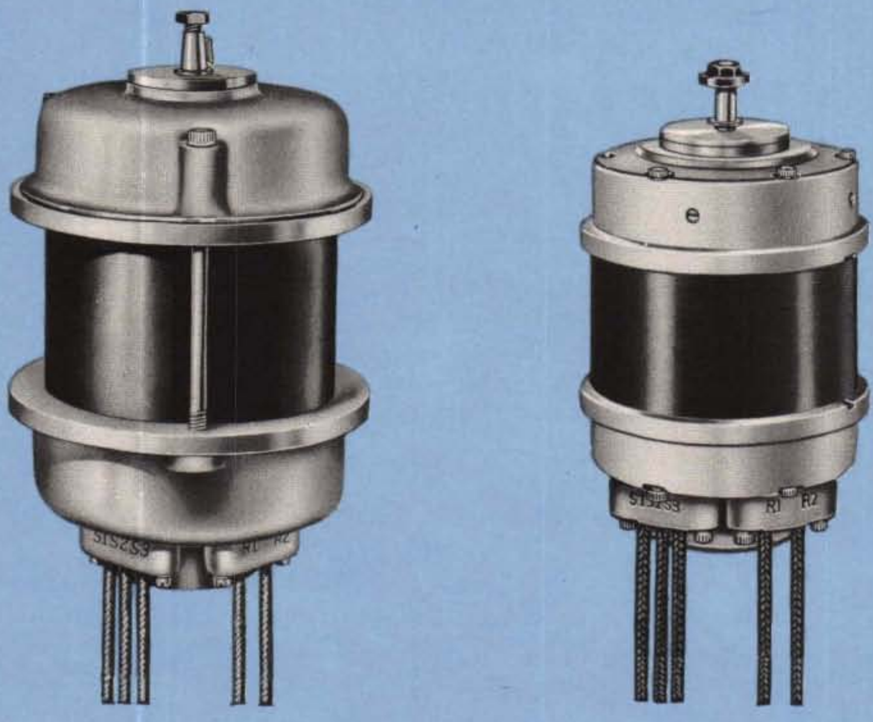
7 To refine the setting, with the power ON, slip through the setting clamp until the readings are the same on both the output and the input counters.



8 Now to check the setting: use a small rod of non-conductive material to push the follow-up contacts first in one direction, and then in the other. The motor should return the output counter to the same reading each time.

9 Tighten the setting clamp after the counter readings are matched.

SYNCHROS



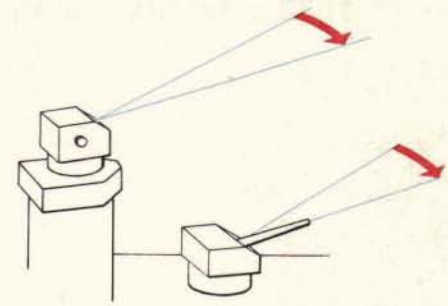
SYNCHRO GENERATOR (TRANSMITTER)

SYNCHRO MOTOR (RECEIVER)

Synchro generators and synchro motors are used at many points in fire control systems to transmit information electrically from one place to another. The generator, or transmitter, sends out signals and the motor, or receiver, receives them.

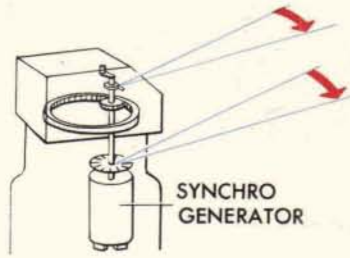
Synchros are connected in such a way that any amount of rotation of the generator rotor will cause the rotor of the motor to turn the same amount.

The receiver either indicates the value of the signal by turning a dial, or controls the action of a servo motor, by means of which the value is used to position other mechanisms in the fire control system.

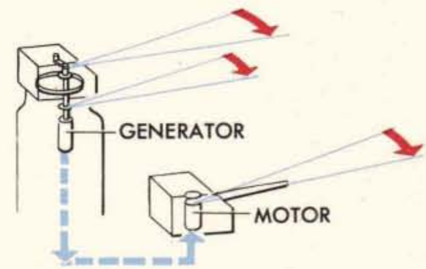


Here's the way they work

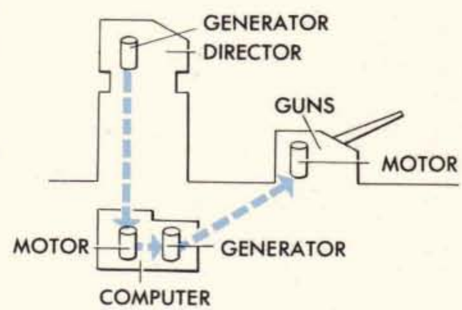
Suppose that it is desired to keep two pieces of equipment, a director and a gun for instance, always pointing in the same direction. Assume that the control is in the director.



When the director is turned, the rotor of a synchro generator (transmitter) geared to the director is turned. A dial may be geared to the synchro generator shaft to indicate the amount the director has turned, but this has nothing to do with transmitting a signal. An electrical signal, representing the amount the transmitter rotor has turned, is transmitted over wires to a synchro motor (receiver) located, in this case, at the gun. This signal causes the rotor of the synchro motor to turn, or attempt to turn the same amount as the generator rotor has been turned.

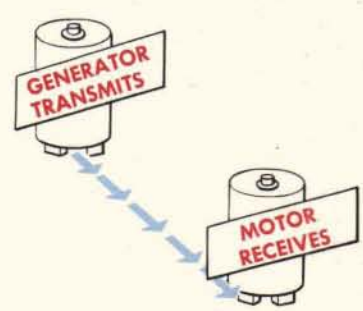


If the synchro motor is connected to a power drive (through a servo system) it will control the drive, and thus cause the gun to turn the same amount as the director is turned.



In most cases a synchro generator in the director transmits signals to a synchro motor in the computer, causing certain computer mechanisms to operate.

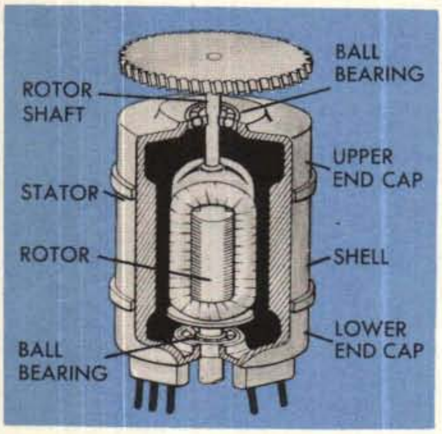
The computer mechanism, in turn, operates another synchro generator and this second generator then sends out signals to a synchro motor in the gun mount.



Synchros team up for many jobs

Data concerning Elevation, Range, Ship Course, and so on are all handled by synchros working in pairs—teams of generator and motor, or two generators and two motors.

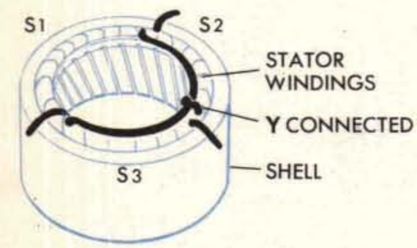
The GENERATOR or TRANSMITTER



A synchro generator, or transmitter, consists of two major parts: a stator and a rotor.

The stator consists of an upper end cap, a "shell"—on the inner side of which are slots containing the stator windings—and a lower end cap.

Ball bearings on the rotor shaft fit into the upper and lower end caps.



How the STATOR is wired

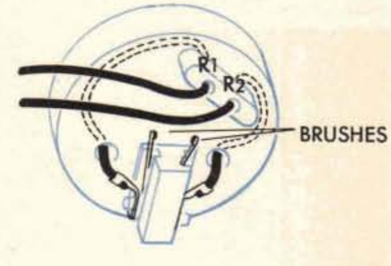
Inside the stator shell are three windings or coils.

By taking a lead wire from one end of each winding, and joining these leads together, a common connection is made.

The coils are now said to be *Y* connected, as the three leads are the arms of a letter *Y*.

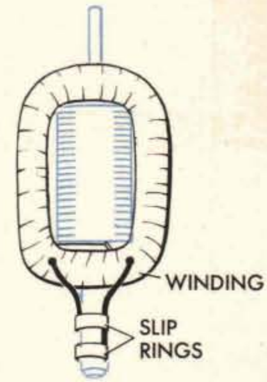
The other end of each winding has a lead wire soldered to it. These lead wires are also labeled *S1*, *S2*, and *S3*, and they pass through a guide block in the lower cap.

How the ROTOR is wired



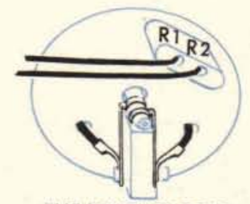
Two carbon composition brushes are assembled inside the lower cap and to these are connected leads labeled *R1* and *R2*.

The rotor has a winding connected to slip rings on its shaft.



When the rotor is assembled in the stator, the two carbon brushes, just mentioned, bear against these slip rings.

In this way, current can be supplied through leads *R1* and *R2* to the rotor winding and the rotor will still be free to turn.



THE BRUSHES BEAR AGAINST THE SLIP RINGS

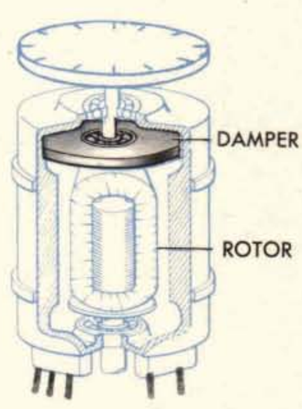
The important parts of the synchro generator are three stator or field coils, with one end of each brought to an outside terminal, and a rotor which can be energized by connecting its two leads directly to an outside source of supply.

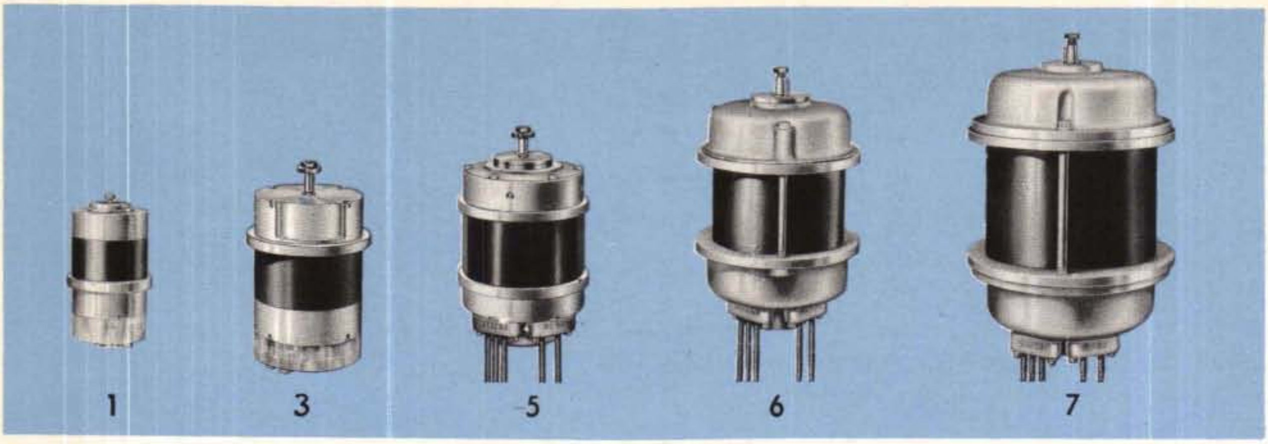
The MOTOR or RECEIVER

The synchro motor, or receiver, is like the synchro generator in construction and electrical operation.

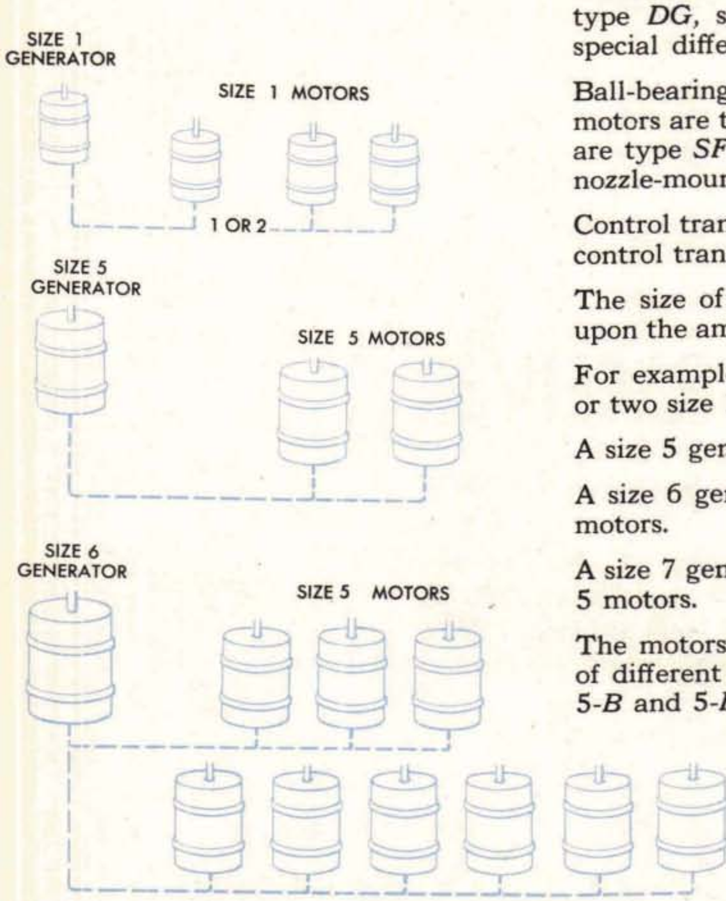
The generator rotor is turned by gearing, and stops as soon as the input ceases. But the rotor of a receiver is turned by electrical signals and, therefore, it may oscillate before coming to rest. Also, certain signals may cause the rotor of a receiver to spin.

To prevent spin, each motor is equipped with a damper. Generators do not have a damper.





There are several sizes and types of synchros



SIZES of synchros are designated by numbers

Synchro Generators in general use are sizes 1, 5, 6, and 7.

Synchro Motors in general use are sizes 1 and 5.

TYPES of synchros are designated by letters

Generators are type *G*, differential generators are type *DG*, special generators are type *SG*, and special differential generators are type *SDG*.

Ball-bearing motors are type *B*, flange-mounted motors are type *F*, special flange-mounted motors are type *SF*, differential motors are type *D*, and nozzle-mounted motors are type *N*.

Control transformers are type *CT* and high-speed control transformers are type *HCT*.

The size of a motor or generator used depends upon the amount of work to be done.

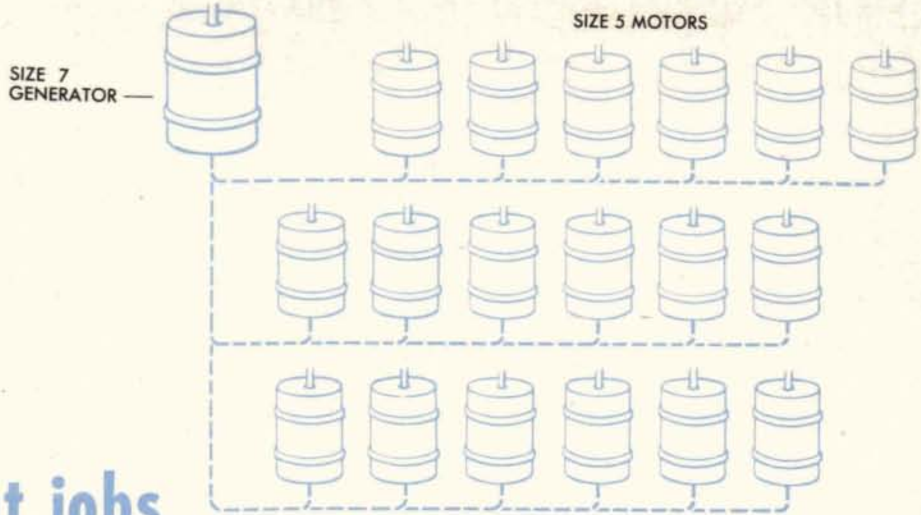
For example, a size 1 generator can control one or two size 1 motors.

A size 5 generator can control two size 5 motors.

A size 6 generator can control up to nine size 5 motors.

A size 7 generator can control up to eighteen size 5 motors.

The motors controlled by one generator may be of different types. The most commonly used are 5-*B* and 5-*F* motors.

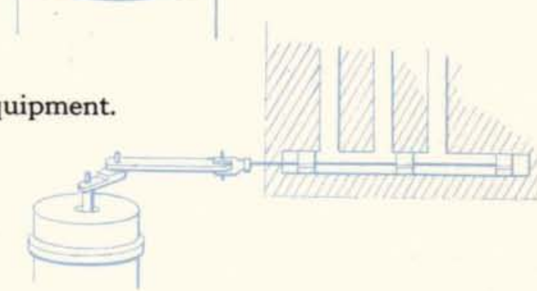


for different jobs

A synchro motor can be used directly to position a dial.

It can do other light work. For example, it can be used to close contacts which control the action of a servo motor.

It can operate pilot valves that control hydraulic equipment.



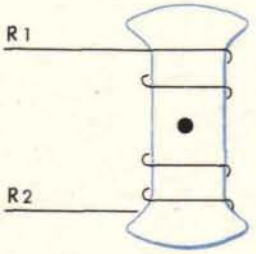
Since synchro motors can be used to operate many types of equipment, the synchro system of transmission provides a versatile form of remote control.

ELECTRICAL OPERATION

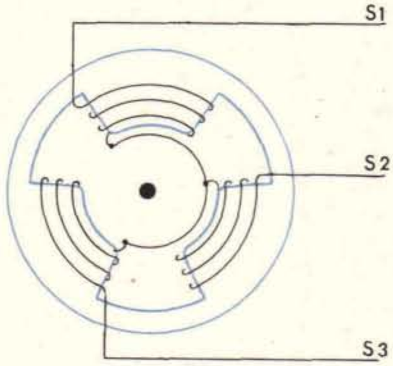
The synchro generator and synchro motor are identical so far as their electrical features are concerned.

The electrical operation of either a generator or a motor can be followed by examining the wiring of a rotor and stator, and describing what happens when current is supplied to the coils.

Here are a rotor and a stator shown schematically:

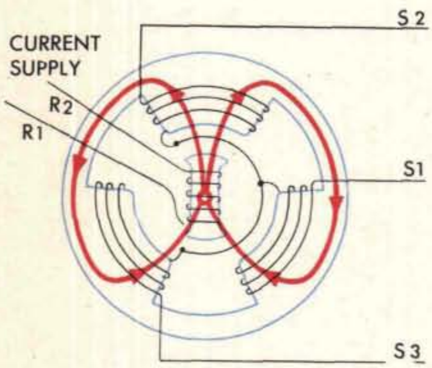


ROTOR



STATOR

How voltage is induced



When current is passed through the rotor winding, the rotor sets up a changing magnetic field.

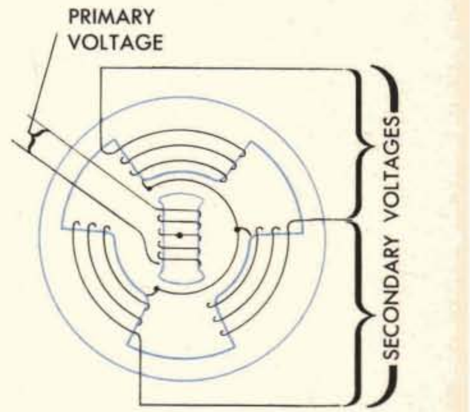
The lines of force in this field cut through the stator coils, and an electrical pressure is induced in each coil.

The electrical pressure is measured in volts. So it can be said that a voltage is induced in each coil.

All the voltages given in this description are the effective voltages. As will be seen later the effective voltage may consist of both a plus and a minus voltage. For example, if a + 52 voltage, induced in one coil, is combined with a −26 voltage, induced in another coil, the connections are such that the effective voltage will be 78 volts. The effective voltage can be read by connecting a voltmeter across any two of the *S* leads.

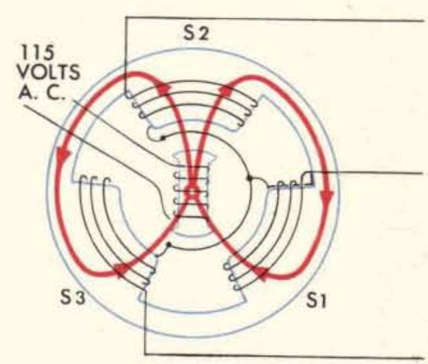
of the SYNCHRO UNIT

The synchro acts like a transformer

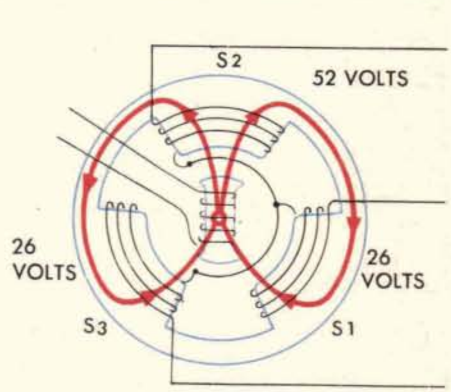


If the voltage applied to the rotor winding from the outside source of supply is called the "primary" voltage, and the voltage induced in the stator coils the "secondary" voltage, it will be seen that synchro operation is based upon the transformer principle.

The current used to energize the rotor is single phase, 60 cycle, 115-volt, A.C. In following what happens in the synchro windings, remember that this current keeps reversing—changing polarity—*120 times each second.* Any description of an electrical condition in the synchro tells what is happening only during a given instant.



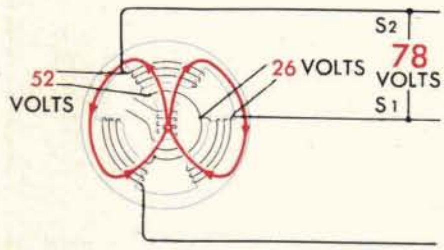
When 115 volts A.C. is supplied to the rotor coils, with the rotor in this position, the lines of force in the magnetic field set up by the rotor will take the directions shown by the arrows. Both sides of the field cut the *S2* winding of the stator, while one side of the field cuts the *S3* winding, and the other side cuts the *S1* winding.



If the induced voltages in the stator windings are measured with a voltmeter, it will be found that 26 volts are induced in the *S3* winding, which is cut by only one side of the magnetic field. A pressure of 26 volts is also induced in the *S1* winding, which too is cut by only one side of the magnetic field. And 52 volts are induced in the *S2* winding, because both sides of the magnetic field cuc this winding.

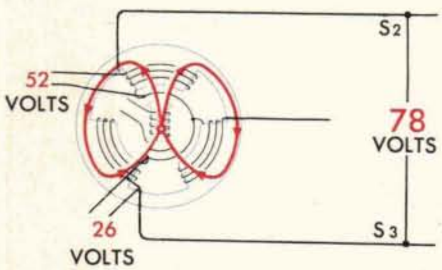
Combining COIL

When one end of the ROTOR is OPPOSITE the S_2 coil

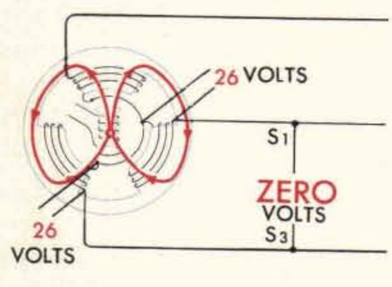


The coils of the stator are Y-connected, so the 52 volts from the *S2* winding add to the 26 volts from the *S1* winding to give a total of 78 volts across the *S2* and *S1* leads.

In addition to indicating the paths of the rotor field the arrows on the diagrams indicate the phase relationship of the three Y connected stator coils. When the arrows passing through a stator coil are going away from the rotor, the coil voltage is in phase with the *R1-R2* voltage. When the arrows through a coil are going toward the rotor the coil voltage is out of phase with the *R1-R2* voltage. When combining the voltages of two coils that are both in phase, or both out of phase, the connections are such that the effective voltage is the *difference* between their two voltages. When combining the voltages of a coil in phase and a coil out of phase, the effective voltage is the *sum* of their two voltages.

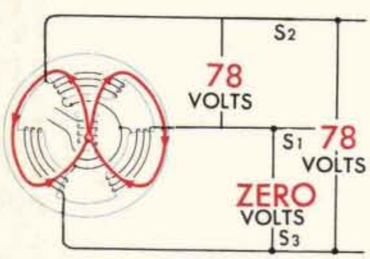


Similarly, the 52 volts from the *S2* winding add to the 26 volts from the *S3* winding to give a total of 78 volts across the *S2* and *S3* leads.



But the 26 volts from the *S1* winding oppose the 26 volts from the *S3* winding, because both coils are out of phase.

This results in zero volts across the *S1* and *S3* leads.



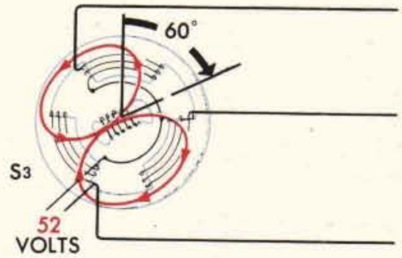
This position of the rotor (when the voltage across *S1* and *S3* is zero and the voltage across *S2* and *S3* is in phase with the *R1-R2* voltage) is known as the electrical zero position. A synchro in this position is said to be on "electrical zero."

It is important to remember the position of a synchro on electrical zero because it is used in installing, testing, and setting.

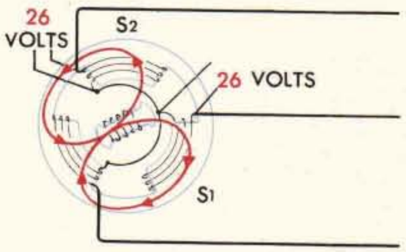
VOLTAGES

When one end of the ROTOR is BETWEEN the S_1 and S_2 coils

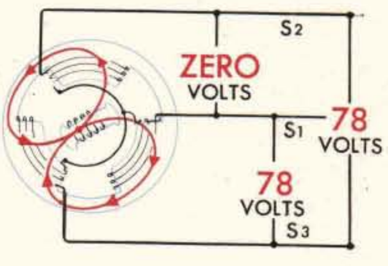
Suppose the rotor is now turned through 60°. The 52 volts are now induced in the *S3* winding, because both sides of the magnetic field are cutting this winding.



Then 26 volts are induced in the *S2* and 26 volts in the *S1* winding.



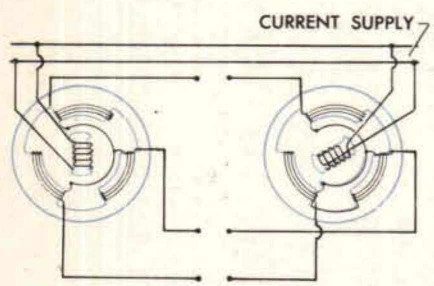
This shows that a change in rotor position changes the voltages of the stator coils.



When the rotor of a synchro *motor* is energized, voltages are induced in the stator coils in just the same way, since, electrically, a synchro motor is constructed on the same principle as a synchro generator.

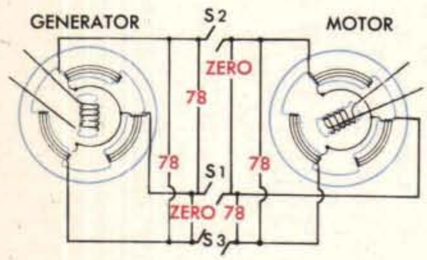
SYNCHRO TEAMWORK

The explanation of the way voltages are induced in the stator coils of both generators and motors, by action of their rotor fields, makes it fairly easy to understand how the motor follows a signal from the generator, when the two units are connected together to work as a team.



Connecting the ROTORS to the current supply

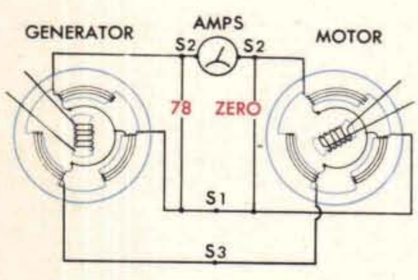
Suppose a generator and a motor are to be connected, and the rotors of each are first connected to the outside source of current supply.



If the rotor of the generator is in zero position, and the rotor of the motor is 60° from zero, the generator and motor will look like this schematically, the stators not yet having been connected.

Voltages across the **GENERATOR** leads will register as 78 volts across *S1* and *S2*, 78 volts across *S2* and *S3*, and zero volts across *S1* and *S3*. Voltages across the **MOTOR** leads will register as zero across *S1* and *S2*, 78 volts across *S2* and *S3* and 78 volts across *S1* and *S3*.

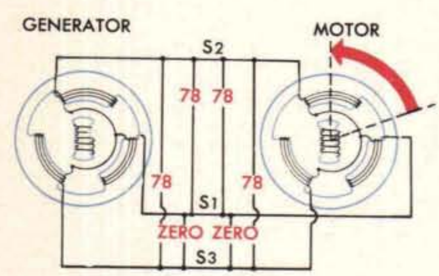
Connecting the STATORS



Now the stators are connected. The *S1* lead of the generator to the *S1* lead of the motor, the *S2* to the *S2* and the *S3* to the *S3*.

Whenever there is a difference of potential between two points which are joined by an electrical conductor, a current will flow.

So with 78 volts registered across one set of leads, and zero volts across another, as in the case of the *S1* and *S2* leads, current will flow when the leads are joined together.



Such a current flow in the stator windings produces a torque, or turning force, on the rotors of both the motor and the generator.

The rotor of the generator is held stationary; it can only turn when the gearing used to transmit signals is turned. But the rotor of the motor is free to move.

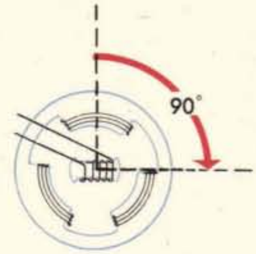
The rotor of the motor, therefore, turns until the voltages from the motor equal those from the generator.

This means that the rotor of the motor turns until both rotors are aligned, for, in this position, the voltages generated in the motor windings are equal to those generated in the generator windings.

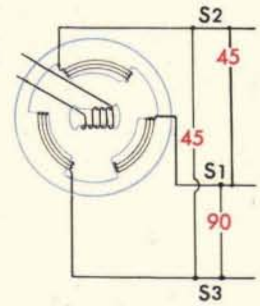
It also means that no more current flows and, consequently, *the torque falls to zero.* The two rotors will remain aligned until the voltages are disturbed again.

Here's another example

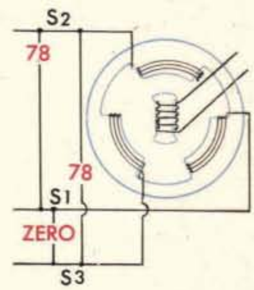
Suppose the rotor of the generator is now turned through 90°.



Voltages measured across the **GENERATOR** leads will read 45, 45, and 90.



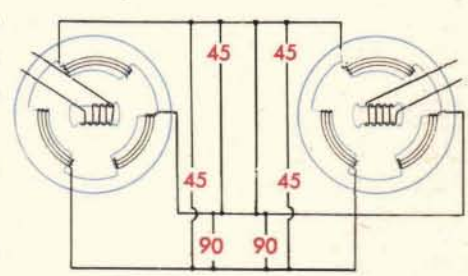
But remember that the voltages across the **MOTOR** leads, with the rotor in zero position, read 78, 78, and zero.



This difference in voltages, between the motor and generator leads, causes current to flow, and the rotor of the motor turns until the voltages across the motor leads equal the voltages across the generator leads.

When there is no difference in the voltages, the two rotors will again be aligned.

Also, voltages being equalized, there is no further current flow. The torque exerted on the rotors is zero, and the rotors will remain aligned until the voltages are again disturbed.



In synchro transmission, any movement of the rotor in the synchro generator produces a corresponding movement of the rotor in the synchro motor. The position of the rotor of a synchro receiver always conforms to the positions of the rotor in a synchro transmitter.

SYNCHRO DIFFERENTIAL GENERATORS

SYNCHRO DIFFERENTIAL GENERATOR

SYNCHRO DIFFERENTIAL MOTOR

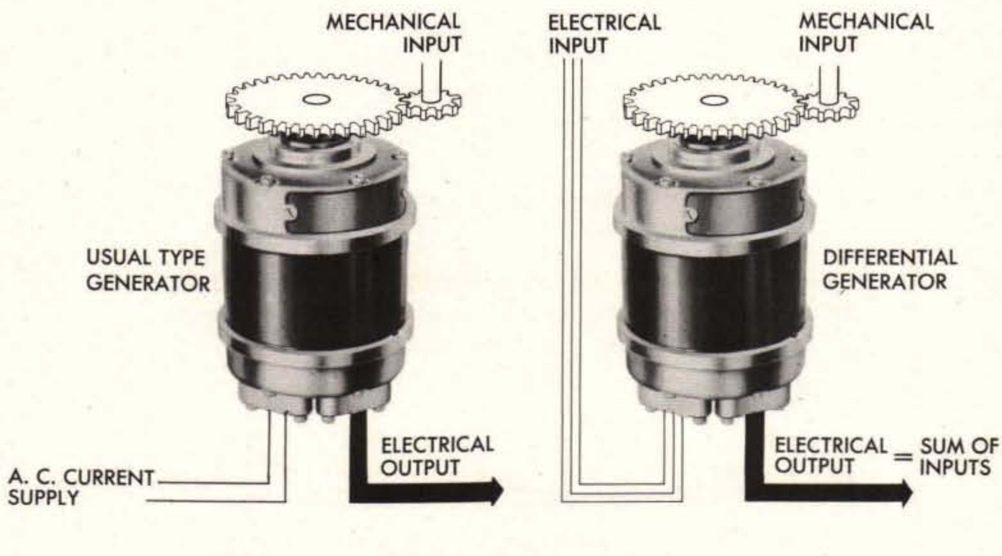
DIFFERENTIAL GENERATOR

The difference between a synchro *differential* generator and the usual type of synchro generator is this:

The usual type of generator transmits the value of a signal which is cranked in mechanically.

The differential type generator transmits the sum of two values. One is cranked in mechanically; the other is fed in electrically from a regular generator. Mechanical and electrical inputs may be put in separately or simultaneously.

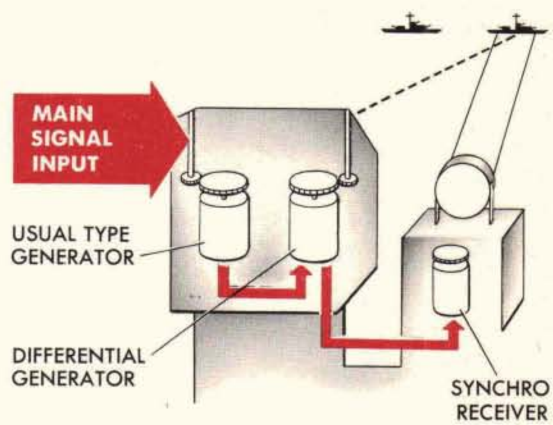
The differential generator obtains inputs from two separate sources and transmits the sum of these inputs to a synchro motor, which positions whatever mechanism is being handled.



and MOTORS

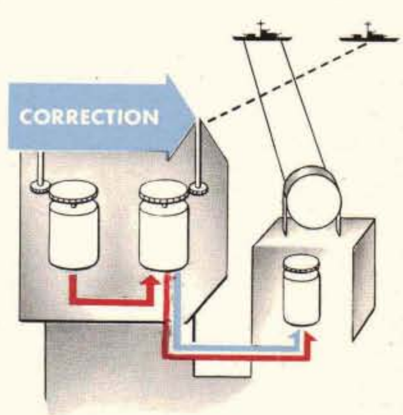
The synchro differential in action

Suppose a searchlight is synchronized so that it trains with a director. The synchro hook-up can be arranged as shown here. A usual type generator, geared to the director, transmits a signal to a differential generator (here shown as located in the director).



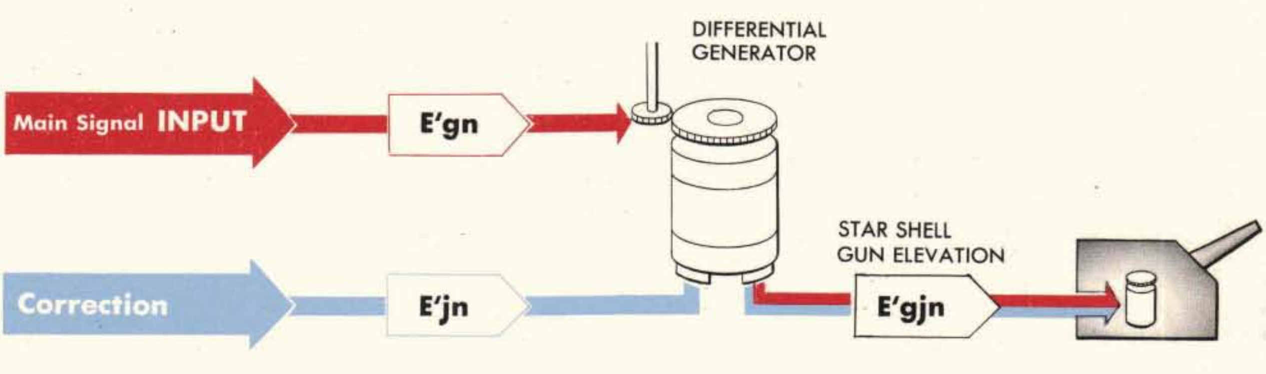
If no other input is set into the differential generator, the signal passes on unchanged to the synchro receiver controlling the mechanism which controls the searchlight, and the searchlight is trained, exactly as the director trains. The searchlight, therefore, points to the exact spot on which the crosswires of the pointer's and trainer's telescopes are registered. (Parallax has been ignored.)

If a value is now set into the differential generator by hand, the total value of the signal transmitted to the synchro receiver changes, and the position of the searchlight changes, even though the director remains stationary.



In this way, the searchlight can be trained independently of the director when desired. Here, for instance, the searchlight has been trained away from the ship on which the director is trained to a second ship, which is following.

Another example of the use of a differential generator is found in star shell fire. The main gun elevation signal is computed and cranked into a differential generator, mechanically. A correction for elevation—or elevation spot—is fed in electrically. The sum of these two values forms the output signal which is final gun elevation order.

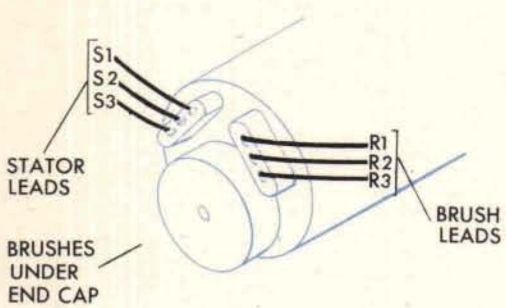


The 3-PIECE SYNCHRO TEAM

The differential generator looks like the usual type of synchro generator. Actually, the stator is the same. The difference lies in the rotor.

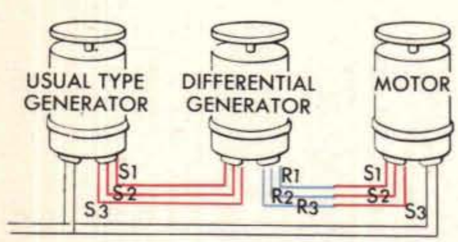
The rotor has three windings on a slotted core. The windings are Y-connected.

One end of each winding is connected to a slip ring on the rotor shaft.



Three brushes, assembled in the lower end cap of the generator, bear against the slip rings, and the leads connected to these brushes are labeled *R1, R2, R3*.

The 3-piece synchro team, which is formed with the differential generator, is wired as indicated here. Note that the differential generator is not connected to the 115-volt A.C. supply.



The *S1, S2,* and *S3* leads of the usual type generator, which is now called merely the "generator," for simplicity, are connected to the stator of the differential generator.

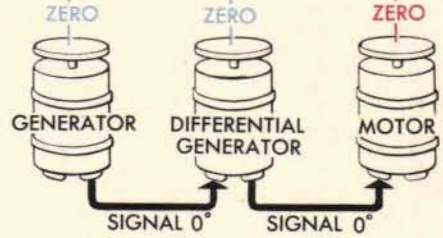
And the *R1, R2,* and *R3* leads, from the rotor of the differential generator, are connected to the three stator leads of the motor.

How it works

Example 1

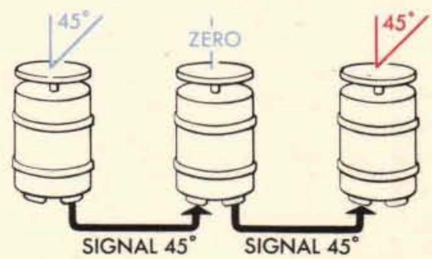
Suppose the generator is set on zero, and the differential generator is also set on zero.

The motor dial registers zero, because no signal is being transmitted.

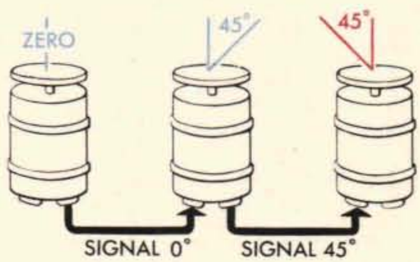


Suppose the rotor of the generator is turned 45° clockwise, while the differential rotor is held stationary on zero by means of the input gearing.

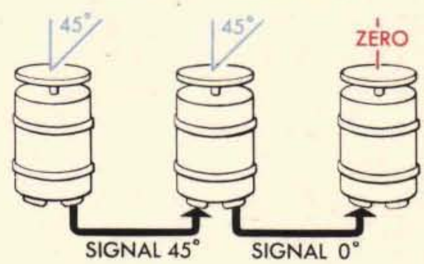
The rotor of the motor turns 45° clockwise because the signal has been transmitted through the differential generator from one end of the hook-up to the other without being changed at any place along the route.



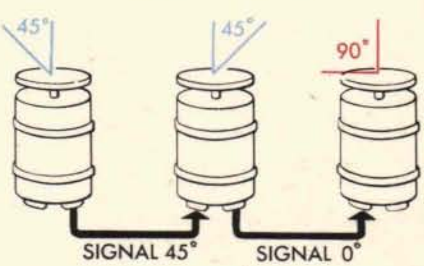
Now if the *generator* rotor is held at zero, and the *differential generator* rotor is turned 45° *clockwise,* the rotor of the motor will turn 45° *counterclockwise.*



Suppose now that the rotor of the generator is turned 45° clockwise. The rotor of the motor will return to zero, because the 45° signal from the generator now cancels the signal from the differential generator.



If, however, the rotor of the generator is turned 45° counterclockwise, while the rotor of the differential is held at 45° clockwise, the rotor of the motor will turn 90° counterclockwise. This is because the signal from the generator is now added to the signal from the differential generator.



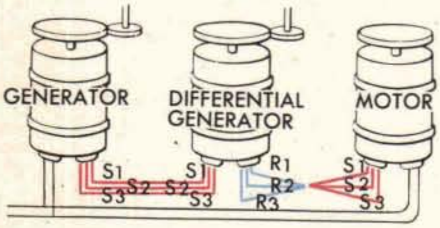
The motor will be positioned by:

1 The sum of the two inputs if they are in opposite directions.

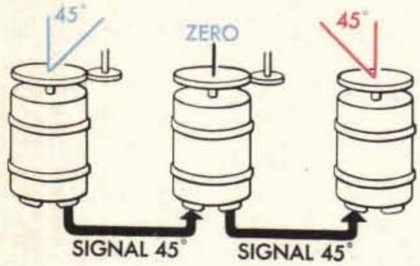
2 The difference between the two inputs if they are in the same direction.

More about how it works

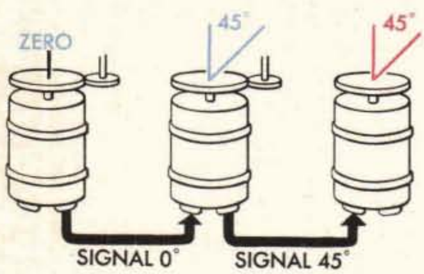
Example 2



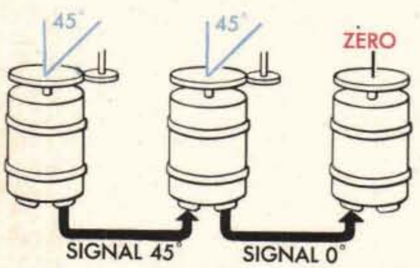
When the *R1, R2,* and *R3* leads from the rotor of the differential generator are crossed, so that the *R1* lead is connected to the *S3* stator lead of the motor, and *R3* to the *S1* stator lead, as shown here, then results will be obtained as follows:



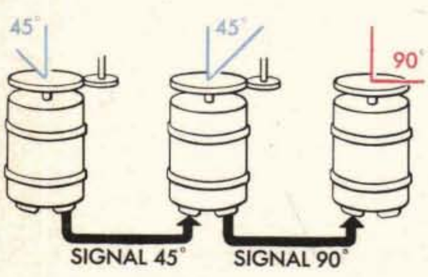
If the rotor of the generator is turned 45° clockwise, while the differential rotor is held at zero by input gearing, then the rotor of the motor turns 45° counterclockwise.



If the generator rotor is held on zero, and the differential generator rotor turned 45° clockwise, the rotor of the motor will turn 45° clockwise.



Suppose now that the rotor of the generator is turned 45° clockwise. The rotor of the motor will turn to zero—as the signal from the generator cancels the signal from the differential generator.



If, however, the rotor of the generator is turned 45° counterclockwise, while the differential is held at 45° clockwise, the rotor of the motor will turn 90° clockwise.

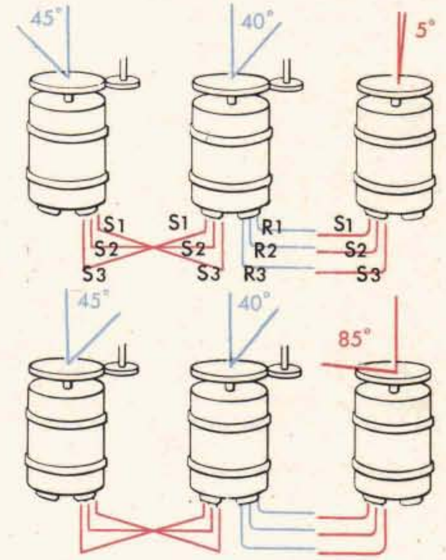
This hook-up results in the rotor of the motor turning in the opposite directions to those shown in the previous example.

Example 3

When the stator leads of the generator and the stator leads of the differential generator are crossed, as indicated here, the rotor of the motor turns in such a direction that the reading on the motor dial is the sum of the generator and differential generator readings in the opposite direction to the generator.

For example, if the rotor of the generator is turned 45° counterclockwise, and the rotor of the differential 40° clockwise, the rotor of the motor will turn 5° clockwise.

And if the rotor of the generator is turned 45° clockwise while the rotor of the differential is held at 40° clockwise, the rotor of the motor will turn 85° counterclockwise.

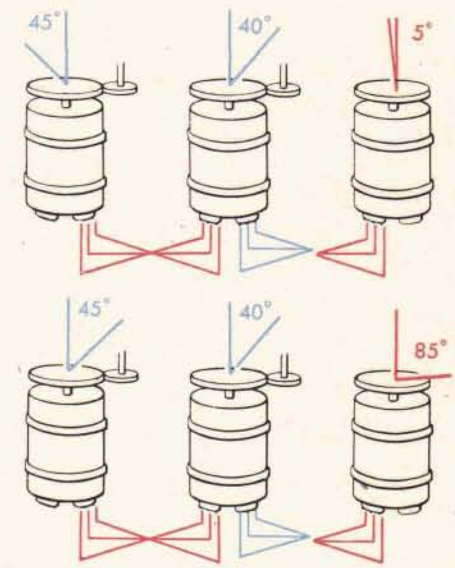


Example 4

When both sets of leads are crossed, as shown here, the rotor of the motor turns in such a direction that the reading on the motor dial represents the sum of the generator and differential generator readings in the same direction as the generator.

For example, if the generator rotor is turned 45° counterclockwise, and the differential rotor is turned 40° clockwise, the rotor of the motor will turn 5° counterclockwise.

And if the rotor of the generator is turned 45° clockwise, while the differential is held 40° clockwise, the rotor of the motor will turn 85° clockwise.



SUMMARY:

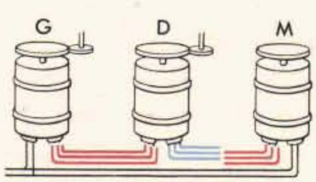
The results of these various hook-ups can be summarized in four equations. In these equations

$G =$ Generator rotor angle

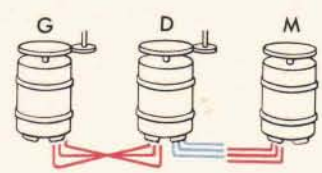
$D =$ Differential generator rotor angle

$M =$ Motor rotor angle

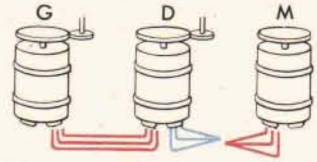
Clockwise rotation is represented as *plus* and counterclockwise rotation as *minus.*



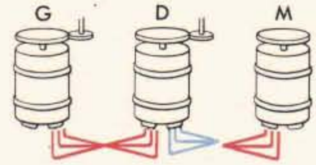
$G - D = M$
OR
$M = G - D$



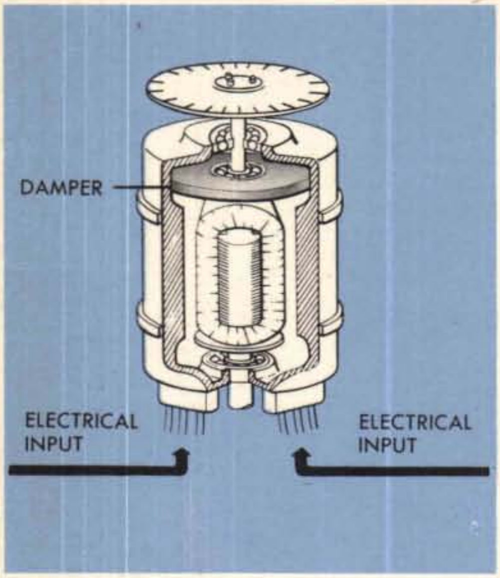
$G + D = -M$
OR
$M = -G - D$



$G - D = -M$
OR
$M = D - G$

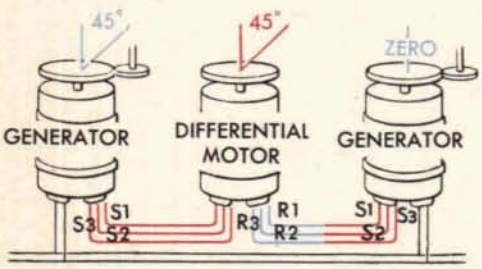


$G + D = M$
OR
$M = G + D$



The DIFFERENTIAL

The synchro differential motor is designed like the differential generator. The only difference is that it has a damper to prevent oscillation and spin.

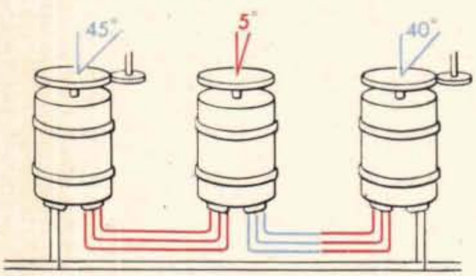


The synchro differential motor receives two electrical inputs from two synchro generators.

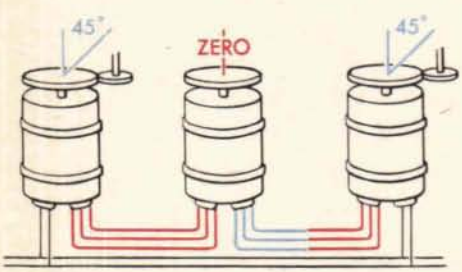
If the synchro team is wired, as shown here, operation will be as follows:

When the rotor of one generator is turned 45° clockwise, the rotor of the differential motor turns 45° clockwise.

The rotor of the second generator being on zero, it transmits no change of signal.

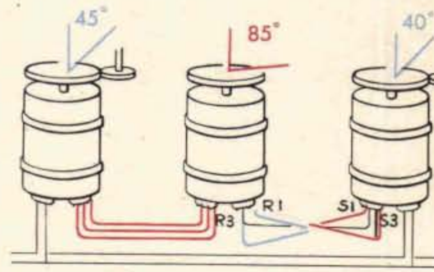


When the rotor of the first generator is turned 45° clockwise, and the rotor of the second generator is turned 40° clockwise, the rotor of the motor indicates 5° clockwise. This is because the rotors of the second generator and the motor turn in opposite directions. The signal of 45° clockwise from the first generator is partially cancelled by the signal from the second generator, which causes the dial on the motor to turn counterclockwise.



If both generator rotors are turned 45° in the same direction the motor will remain at zero, the signal from the first generator cancelling the signal from the second.

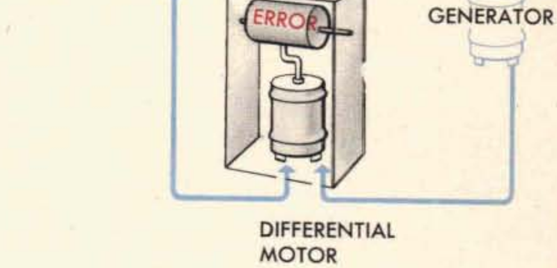
MOTOR



If the synchro setup is wired as shown here, the values of 45° and 40° transmitted by the generators will be added together, and the rotor of the motor will turn through 85°.

To summarize: Either the difference between two transmitted values, or the sum of two transmitted values, can position the differential motor.

An example of how the differential motor is used is found in a testing device called an Error Recorder. This device uses a differential motor to measure continuously the difference between the *signal* to a given mechanism, and the *actual position* of that mechanism. Here is one of the ways it can be used:

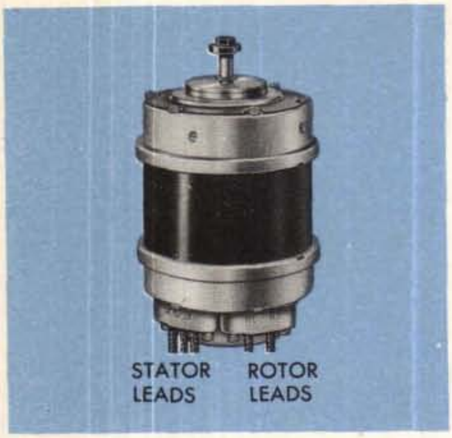


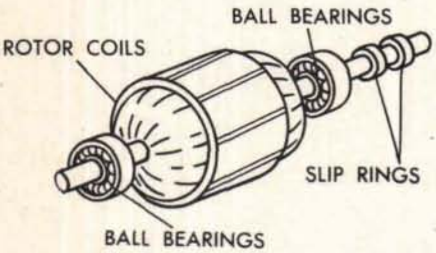
A mechanism known as a dummy director drives a synchro generator which transmits a train signal to position a gun. The same signal goes to one side of the differential motor in the error recorder.

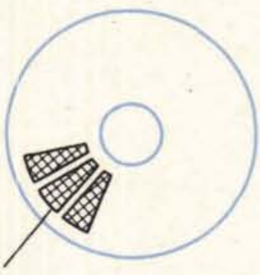
As the gun trains, it drives a synchro generator. This generator sends a signal to the other side of the differential motor.

The difference between the position of the generator in the dummy director and the generator driven by the gun is shown by the differential motor. This difference is the error in gun train.

The CONTROL TRANSFORMER







CROSS SECTION OF CONTROL TRANSFORMER ROTOR

The control transformer is another kind of synchro. Both the synchro motor and the control transformer receive information electrically from a synchro generator, but their outputs differ.

The synchro motor output is the *rotation* of the rotor shaft.

The control transformer output is a *voltage* induced in the rotor coils.

The stator of the control transformer is similar to the stators of other synchro units, but the coils are wound with more turns.

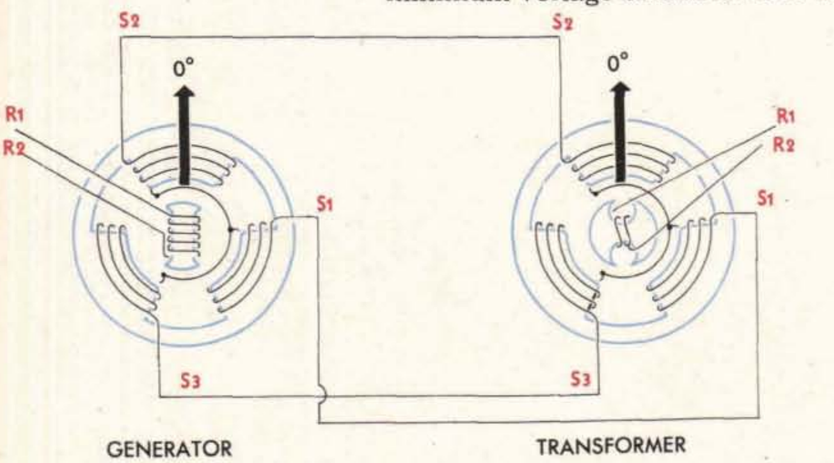
The rotor winding of the control transformer, however, while it resembles that of a differential synchro in appearance, differs considerably from the rotor winding of other types of synchros. It consists of a number of coils which are set in slots around the rotor, and although these coils are connected in series like the coils of other types of synchro rotors, the manner in which the turns are located around the rotor is a characteristic of the control transformer.

The two ends of the rotor winding are connected to slip rings on the shaft. Brushes which bear against these slip rings are connected to *R1* and *R2* leads, as in the case of standard synchro units.

The diagram below shows a generator and control transformer hook-up.

Note that when the rotor of the generator is in "electrical zero" position it lines up with the *S2* winding of its stator; but when the rotor of the control transformer is in zero position it is turned at 90° to the *S2* winding.

It will be remembered that, at point of synchronism, the rotor of a synchro motor takes a position which induces the proper maximum voltages in the stator coils—equal and opposite to the voltages produced by rotation of the generator rotor. However, when the rotor of a control transformer is brought to its position of synchronism, or "correspondence" as it is called, a minimum voltage of almost zero is induced in the rotor.

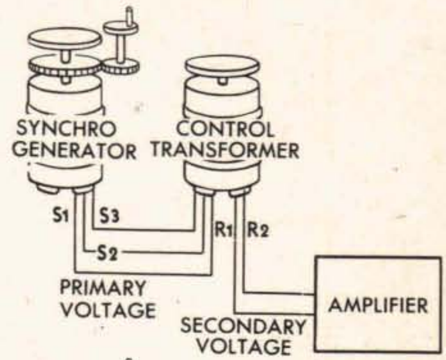


THE TRANSFORMER ROTOR COILS ACT AS IF THEY WERE CONCENTRATED IN ONE COIL WOUND AS SHOWN HERE.

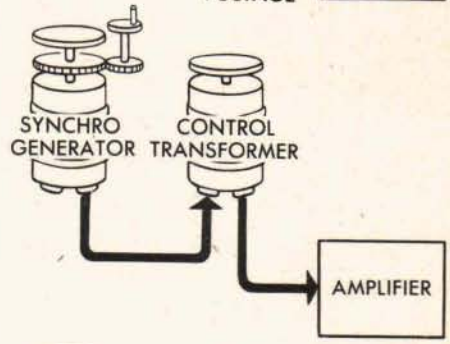
How a control transformer is used

A control transformer, like a synchro motor, is teamed to work with a synchro generator.

The rotor of the control transformer is NOT connected to the power supply. Instead, the *R1* and *R2* leads are usually connected to vacuum tubes in a power amplifier circuit.

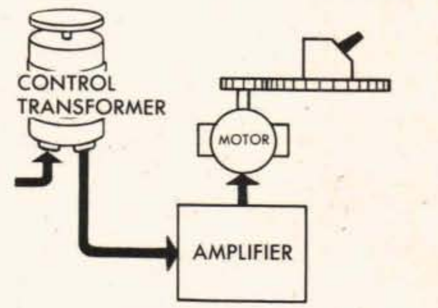


The stator of the generator supplies a primary voltage to the stator of the transformer, and the stator coils in the transformer induce a secondary voltage in the transformer's rotor winding. This secondary voltage is transmitted over the *R1* and *R2* leads to the amplifier. Thus the synchro generator supplies a signal to the transformer, and the transformer, in turn, operates the amplifier.

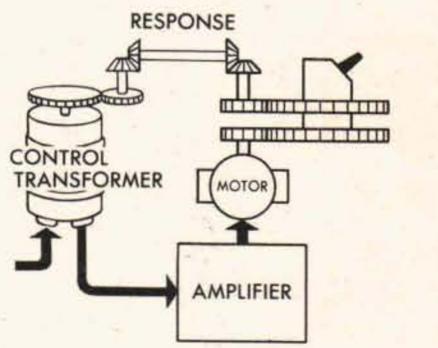


The amplifier controls a power motor, which is used to train a gun, or a searchlight, or to rotate other mechanisms. The object which is trained or rotated—in this example, a gun—is geared to the rotor of the control transformer. As the motor runs, rotation of the gun acts through this response gearing and turns the rotor of the transformer. When the rotor of the transformer has been turned an amount equal to the signal from the generator, the output voltage of the control transformer drops to zero, causing the power motor and gun to cease turning.

In a similar manner, the gun can be elevated or depressed.

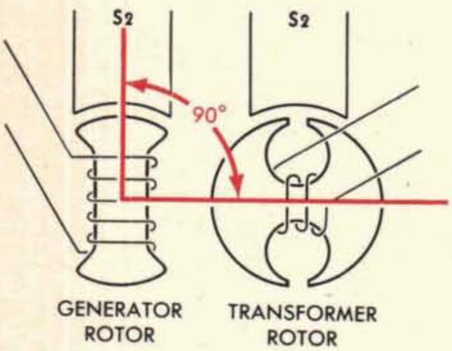


Difference between a control transformer and other synchro units



1. When the stator coils of a control transformer are energized by the generator they do not turn the rotor. They merely induce a voltage in the rotor. It is this voltage, not rotor movement, which signals a mechanism.
2. Because the rotor does not turn in signalling a mechanism, rotor bearing friction does not affect the signal.
3. The rotor of a control transformer is turned *mechanically* by the response line from the mechanism being controlled.
4. Whatever the position of the rotor, the transformer rotor windings are so arranged that, the currents induced in the rotor do not affect the currents that flow in the stator.
5. A synchro generator can drive fewer control transformers than synchro motors, because a control transformer is not connected to the power supply. All of the energy needed by a control transformer must be supplied from the stator of the synchro generator.

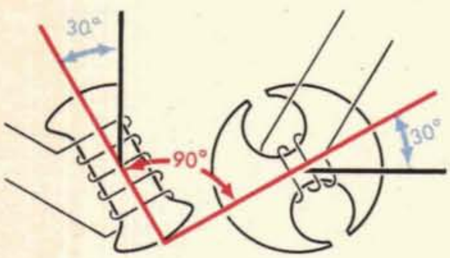
How the control transformer operates



To understand how the control transformer operates, it is best to start with the synchro generator and the transformer on elecrical zero.

The generator rotor lines up with the *S2* winding when in zero position, whereas the transformer rotor is turned 90° from its *S2* winding. The transformer rotor coil, therefore, lies at right angles to the generator rotor coil.

Whenever the two rotor coils are at right angles to each other, they are said to be *in correspondence.*



No matter to what position the generator rotor may be turned, the rotor of the transformer can be turned to bring the rotors into correspondence. For instance, here the generator rotor has been moved 30° from its zero position. By rotating the transformer 30° also, the two rotors are again brought into correspondence.

When the rotor of the generator is turned, four things happen in the transformer.

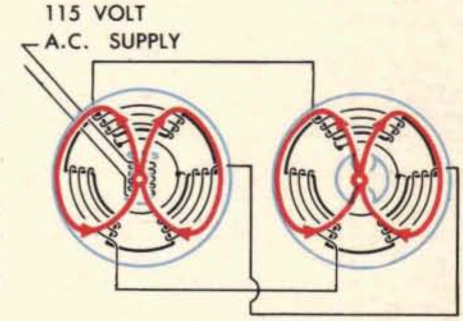
1 The magnetic fields in the generator and transformer rotate.

2 Voltage is induced in the transformer rotor.

3 Polarity of the transformer rotor leads, with respect to the voltage energizing the generator rotor, is established.

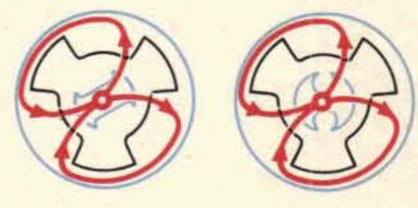
4 The transformer rotor is rotated toward the position of correspondence by the response gearing.

Magnetic fields



The magnetic field set up by the rotor of a synchro generator, when it is supplied with 115 volts A.C., cuts the stator windings of the generator and induces voltages in them.

When the generator is connected to a control transformer, these voltages are transmitted to the stator windings of the transformer and a similar magnetic field is set up in the transformer, just as in the case of the synchro motor.



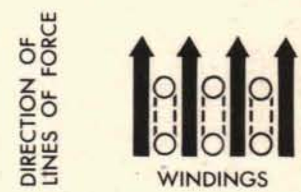
If the rotor of the generator is turned clockwise, the generator field rotates clockwise.

The transformer field also turns clockwise *by an equal amount* because the transformer field is set up by the generator field.

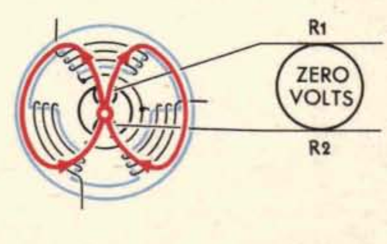
GENERATOR TRANSFORMER

If the rotor of the generator is turned counterclockwise, both fields also rotate counterclockwise the same amount.

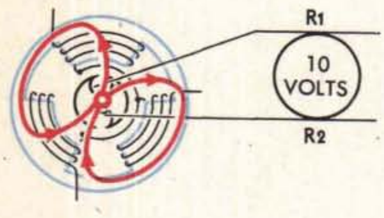
The transformer's field movement depends upon rotation of the generator rotor, and takes place regardless of the position of the transformer rotor.



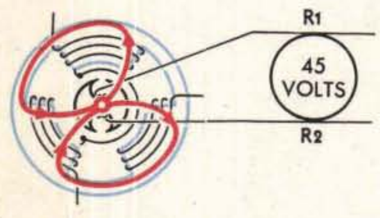
When the rotor of the transformer is in correspondence with the rotor of the generator, a voltmeter will show almost zero voltage (0.03 to 0.3 volts) across *R1* and *R2*. This is because the coils of the rotor winding are lying parallel to the path taken by the lines of force (or flux) of the magnetic field. In this position, the lines of force do not cut the coils, and only a minimum of voltage, due to small eddy currents, is produced.



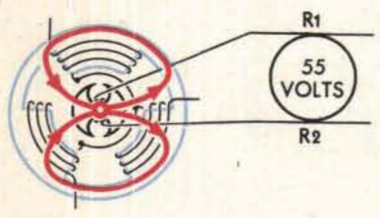
Change of VOLTAGE of the transformer rotor leads



When the field is turned 10°, approximately 10 volts are measured across *R1* and *R2*.



When the field is turned 60°, approximately 45 volts are measured across *R1* and *R2*.



When the field is turned 90°, approximately 55 volts are measured across the rotor leads. This is the maximum voltage which can be induced in the rotor winding of the transformer.

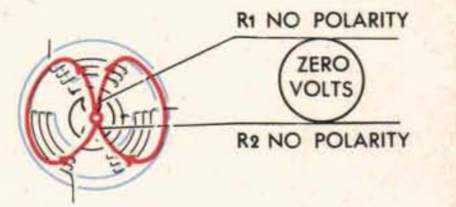
When the field is turned 180°, the transformer's output voltage falls to its minimum. The coils of the rotor winding are again parallel to the lines of force of the stator field, and the transformer rotor is once more in correspondence. When the field is turned 270°, the output voltage rises to its maximum of 55 volts. At 360°, the output voltage is again at a minimum because it is then at the same position as at 0°. There are, therefore, two points in the rotation of the field, 0° and 180°, at which the output voltage from the transformer rotor is at a minimum.

If the field is rotated the same amounts counterclockwise, instead of clockwise, from either the 0° or 180° position, the same voltages will be obtained. This means that for a given amount of rotation, equal voltages will be obtained regardless of the direction in which the field is rotated. However, polarity will change as the field is rotated through the two points of correspondence which lie 180° apart.

Summing up:

1. When the rotors ARE in correspondence, *there is minimum voltage* (almost zero) across the transformer rotor leads.
2. When the rotors are NOT in correspondence, *there is more than minimum voltage* across the transformer rotor leads.

Change of POLARITY of the transformer rotor leads

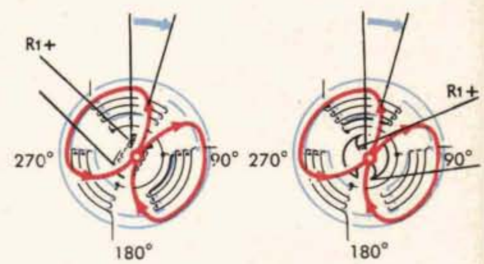


The position of the magnetic fields in relation to the rotor zero position determines the polarity of the transformer's rotor leads.

When the coils of the transformer rotor winding lie parallel to the path taken by the lines of force, there is no voltage across *R1* and *R2*. Because there is no voltage, there can be no polarity.

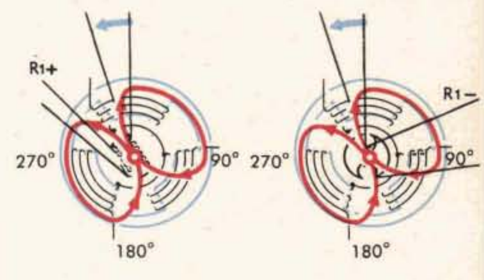
When the rotor of the generator is turned clockwise from the rotor zero position, both magnetic fields turn clockwise, and a voltage is set up across the transformer's *R1* and *R2* leads.

If the polarity of this voltage, at a given instant, is positive when the energizing voltage to the generator rotor is positive, then lead *R1* of the transformer is plus when lead *R1* of the generator is plus. The induced voltage across the transformer leads is in phase with the A.C. supply to the generator rotor.



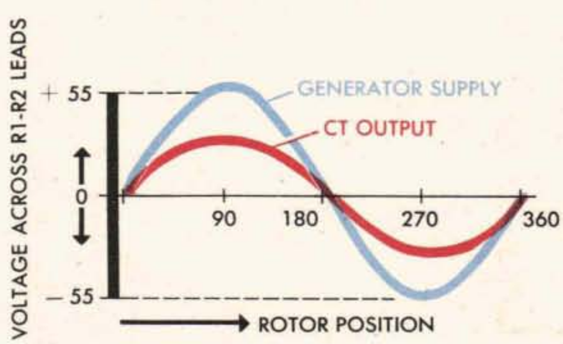
GENERATOR TRANSFORMER

When the generator rotor is turned counterclockwise from the rotor zero position, the voltage across the *R1* and *R2* leads of the control transformer will be negative at the instant the energizing voltage applied to the generator rotor is positive. The voltage from *R1* to *R2* on the control transformer will be 180° out of phase with the A.C. voltage from *R1* to *R2* on the generator. The polarity of lead *R1* of the transformer is now minus when lead *R1* of the generator is plus.

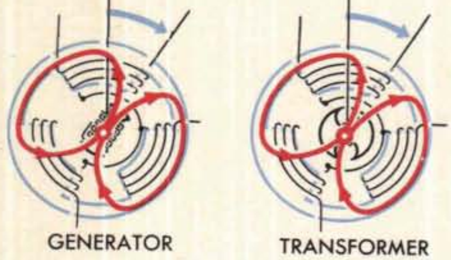


The polarity of the control transformer output voltage is determined by the position of the magnetic fields in relation to the rotor zero position.

It has now been established that the output of the control transformer is a voltage which varies in magnitude and shifts polarity with the deviation of the transformer rotor from the position of correspondence. This output is a signal which can be amplified by means of a follow-up and used to position mechanisms.



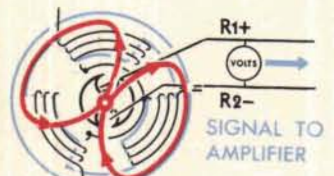
Response



Since almost no voltage is induced in the rotor of the transformer when the generator and transformer rotors are in correspondence (at right angles), voltage from the transformer to the amplifier can be reduced to zero by bringing the transformer rotor into correspondence with the generator rotor.

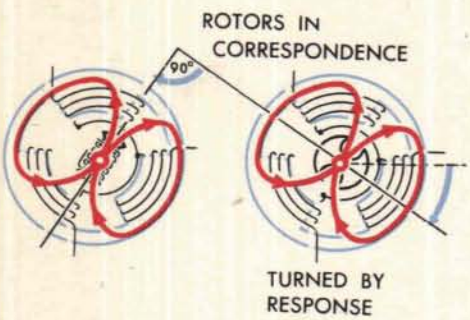
This is done by means of the response gearing.

In this example, an input to the generator has turned the generator rotor clockwise. Consequently, the magnetic fields are turned clockwise.



A voltage is induced in the rotor of the transformer, and this voltage is transmitted to the amplifier.

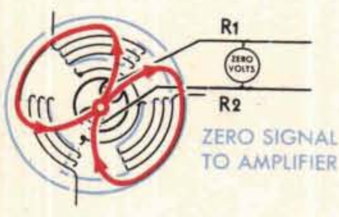
When rotation of the generator rotor stops, the rotation of the magnetic fields stops.



When the transformer rotor is turned by the response until it is in correspondence with the rotor of the generator the voltage across the *R1* and *R2* leads of the transformer falls almost to zero—because the coils of the rotor winding lie parallel to the path taken by the lines of force in the magnetic field.

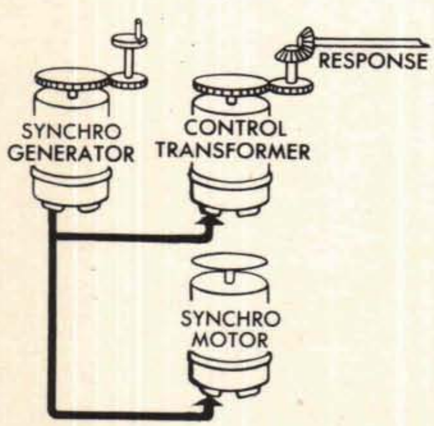
With voltage nearly zero, the signal to the amplifier ceases.

In practice, the rotating of the magnetic fields and the response action are almost simultaneous, which means that the rotor of the transformer is brought into correspondence within a fraction of a second after input to the generator stops. Rotation of the gun, or searchlight, therefore, can be regarded as simultaneous with transmission of the signal.



A control transformer and synchro motor on the same line

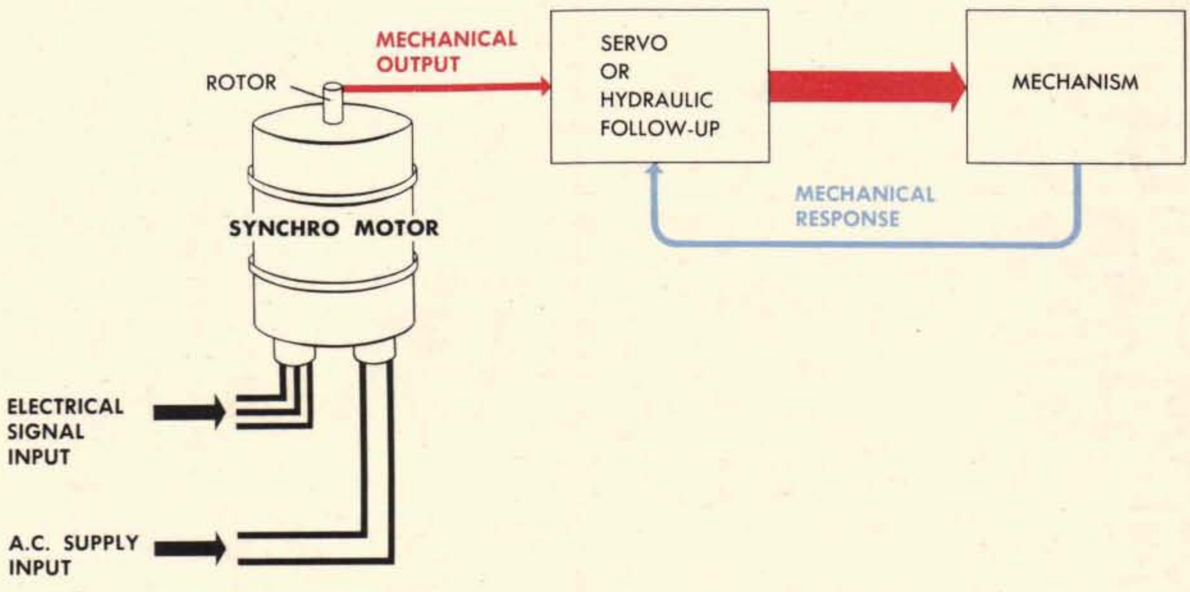
A control transformer can be added to a synchro generator-synchro motor circuit so that both transformer and motor, each positioning separate mechanisms, can receive signals from the same generator.

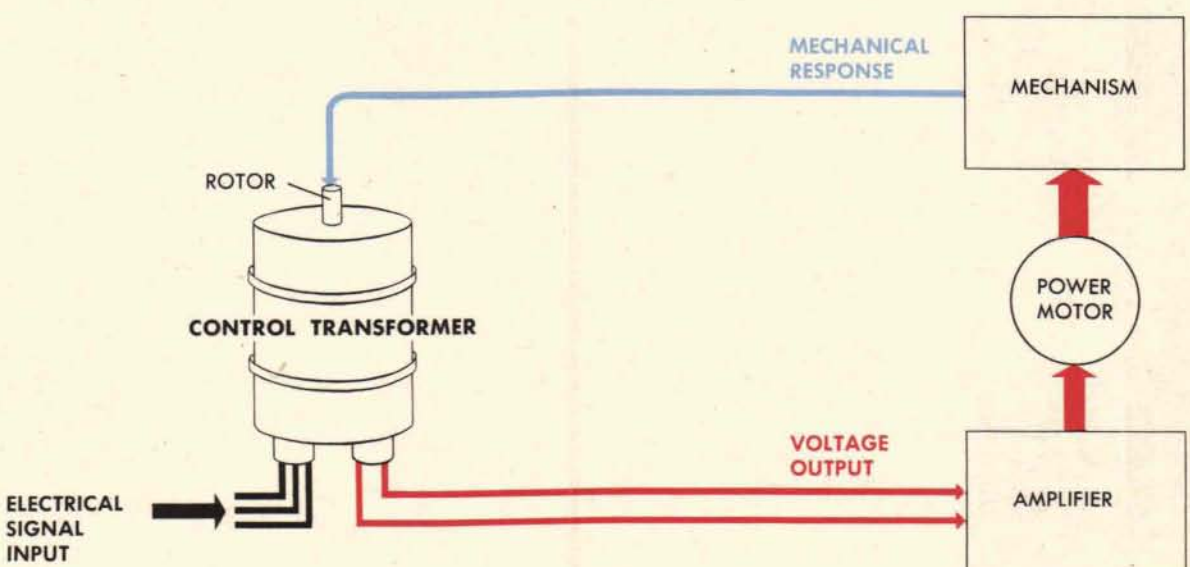


Rotation of the transformer rotor by the response has no effect upon the operation of the motor. This is because the position of the transformer's rotor has practically no effect upon the currents that flow in the transformer stator coils, and therefore there is no "kick back" to the system when the transformer rotor is turned by the response.

From this it can be seen that if the power is shut off at the amplifier, and the gun or the searchlight normally controlled by the transformer is positioned manually, the resulting rotation of the transformer rotor will not affect other transformers or synchro motors connected to the same line.

Comparison between a SYNCHRO MOTOR hook-up and a CONTROL TRANSFORMER hook-up





TYPES of SYNCHRO GENERATORS

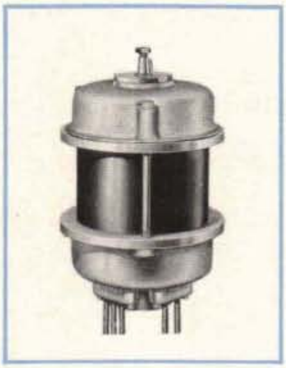
Diameter dimensions given are the maximum outside diameters. Length dimensions are overall (over-the-shaft) lengths.

1G

Shaft Ext.: Tapered
115 V. Pri., 90 V. Sec.
Avg. Error: 0.5 deg.
Max. Error: 1.5 deg.
Length: 3.90 in.
Diam. 2.25 in.

5G

Shaft Ext.: Straight
115 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length: 6.05 in.
Diam. 3.625 in.

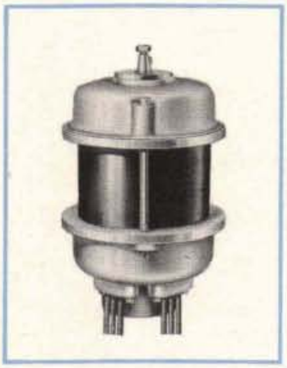


6G

Shaft Ext.: Tapered
115 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length: 7.22 in.
Diam. 4.5 in.

7G

Shaft Ext.: Tapered
115 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length: 8.90 in.
Diam. 5.75 in.



6DG

Shaft Ext.: Tapered
90 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length: 8.53 in.
Diam. 4.50 in.

7DG

Shaft Ext.: Tapered
90 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length: 9.21 in.
Diam. 5.75 in.

•5SDG - 5DG

Shaft Ext.: Straight
90 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length: 6.36 in.
Diam. 3.625 in.

• S denotes special units — in this case 400 cycles.

TYPES of SYNCHRO MOTORS

3F

Shaft Ext.: Straight
115 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length 5.2 in.
Diam. 3.1 in.

1F

Shaft Ext.: Tapered
115 V. Pri., 90 V. Sec.
Avg. Error: 0.5 deg.
Max. Error: 1.5 deg.
Length 3.90 in.
Diam. 2.25 in.

5B

Shaft Ext.: Straight
115 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length 6.77 in.
Diam. 3.39 in.

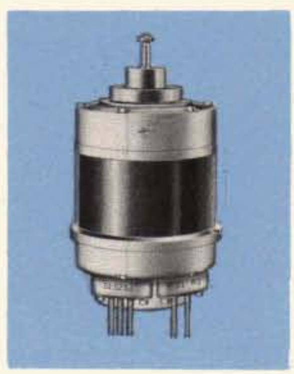
5D

Shaft Ext.: Straight
90 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length 6.35 in.
Diam. 3.625 in.

5F – •5SF

Shaft Ext.: Straight
115 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length 6.05 in.
Diam. 3.625 in.

•S denotes special units – in this case 400 cycles.



•5N

Shaft Ext.: Straight
115 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length 6.63 in.
Diam. 3.625 in.

•N denotes nozzle mounting.

CONTROL TRANSFORMERS

1CT

Shaft Ext.: Straight
90 V. Pri., 55 V. Sec.
Av. Error: 0.166 deg.
Max. Error: 0.5 deg.
Length 3.90 in.
Diam. 2.25 in.

5CT

Shaft Ext.: Straight
90 V. Pri., 60 V. Sec.
▲Avg. Error: 0.12 deg.
Max. Error: 0.33 deg.
Length 6.05 in.
Diam. 3.625 in.

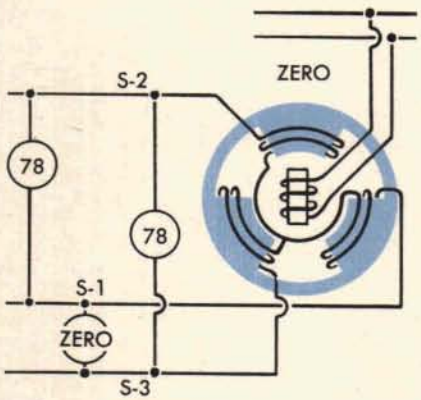
3HCT and **5HCT** are designed for high speed applications. Avg. and Max. Errors same as for *5CT*.

▲Error in control transformers is expressed as degrees of rotation of the magnetic field set up by the currents in the stator.

Setting SYNCHROS

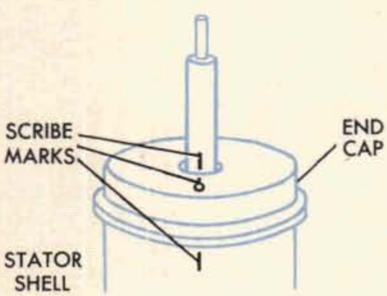
Synchro units are used to transmit values by angular movement. *A common reference point is needed* to which these units may be set before being connected.

In setting synchros, *electrical zero* is used as this common reference point.



The electrical zero point is one of two definite positions of the rotor with respect to the stator. The synchro is in either one of these two positions when the rotor is in such a position that the voltage across the *S1* and *S2* leads is equal to the voltage across the *S2* and *S3* leads, and there is zero voltage across the *S1* and *S3* leads.

A means must be provided to find which of these two positions is the electrical zero position.

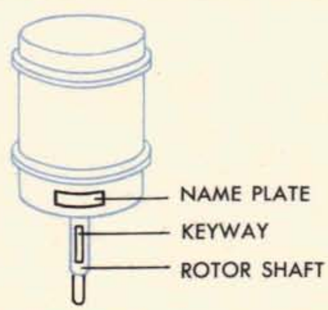


On some synchros *scribe marks* indicate approximately the position of electrical zero. Sometimes the scribe marks cannot be seen when the synchro is installed in the instrument. Some of the older synchros do not have scribe marks. For these reasons it is necessary to know how to find electrical zero.

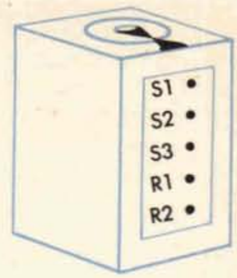
Here are two methods:

The Standard Motor Method

The Electrical Lock Method



NEW FORD GENERATORS ARE APPROXIMATELY ON ELECTRICAL ZERO WHEN THE ROTOR KEYWAY IS LINED UP WITH THE CENTER OF THE NAMEPLATE.

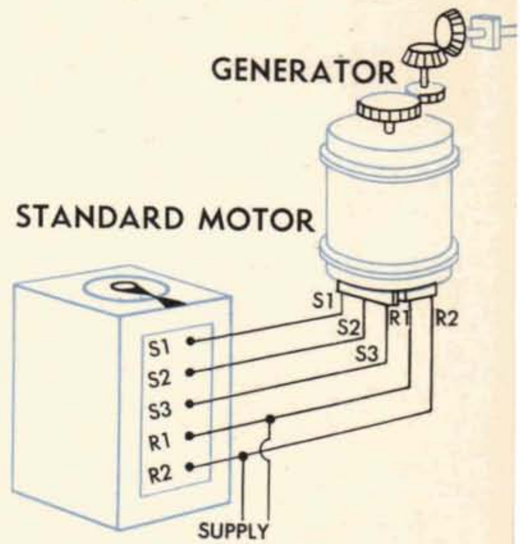


The STANDARD MOTOR METHOD

In the Standard Motor Method a synchro motor that has been accurately set on electrical zero is used to set other synchro motors and generators.

The motor is mounted in a box and has a pointer dial to indicate the position of the rotor. The box has an index mark and when the pointer and the index mark are lined up the motor is at electrical zero.

A button on this box can be pressed down to lock the standard motor at the electrical zero position indicated on the dial.



How to use the standard motor to set a generator

Connect the standard motor to the generator–

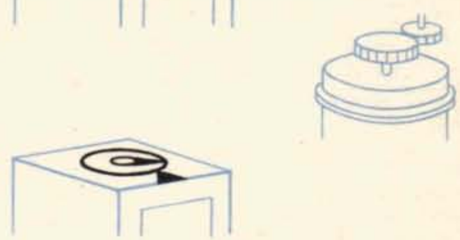
S1 to *S1* *S2* to *S2* *S3* to *S3* *R1* to *R1* *R2* to *R2*

Then supply 115 volts 60 cycle A.C. across *R1* and *R2*.

The rotor of the standard motor will snap into synchronism with the generator rotor and the standard motor dial will indicate the amount the generator is off electrical zero.

Here the standard motor dial indicates the generator is on electrical zero.

Here the standard motor dial indicates the generator is not on electrical zero and should be set according to the instructions on the following page.

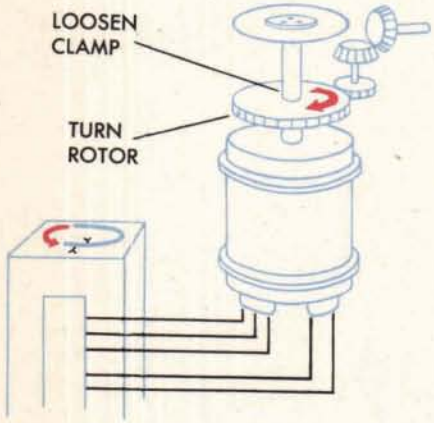


How to use the standard motor to set another motor

The electrical hook-up is exactly the same. The standard motor is locked at zero by means of the push button. This will position the motor that is being set at electrical zero.

To correct when a SYNCHRO is off

There are several ways to correct the setting when a synchro generator is off electrical zero, depending upon the method of clamping.

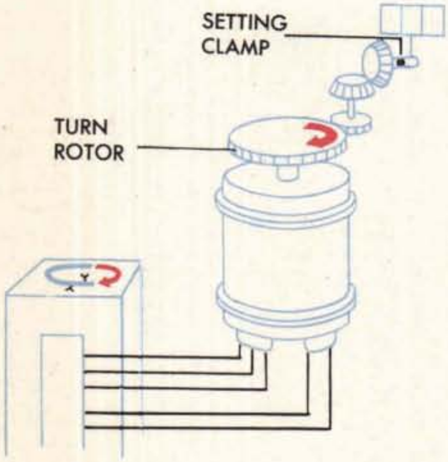


Where a clamping device is used to hold the generator dial to its rotor, loosen the clamping device and turn the rotor.

The generator will transmit a signal to the standard motor causing its dial to turn.

Turn the generator rotor until the standard motor dial reads zero.

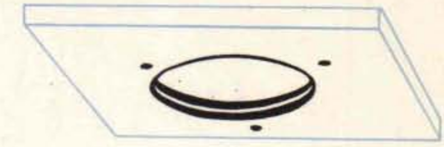
Tighten the clamping device with the generator dial and standard motor dial both on zero.



Where a setting clamp connects the generator rotor to its dial or counter, loosen the clamp and turn the rotor and gearing until the standard motor dial reads zero.

With the standard motor dial reading zero, position the generator dial or counter on zero. Tighten the setting clamp.

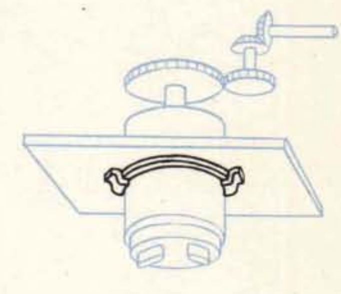
ELECTRICAL ZERO



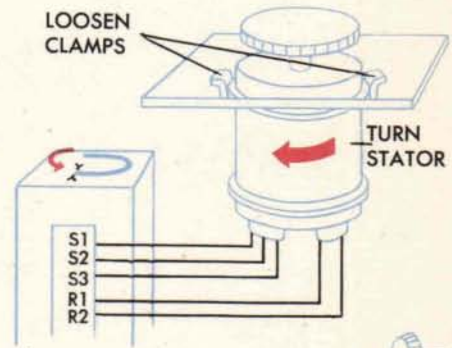
Some installations do not have a dial clamping device. Then the correction is made by changing the mounting of the synchro.

Here is a typical synchro mount.

A plate is machined so that it has a hole with a shoulder all the way around.

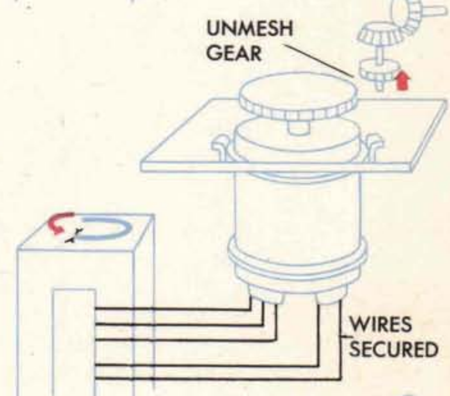


The flange on one of the end caps fits into the hole and is held against the shoulder by clamps that hold the synchro in place.

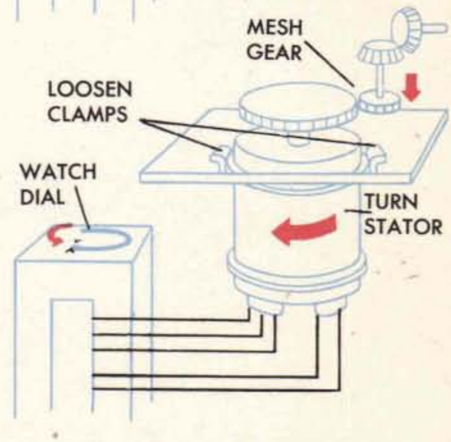


If the motor dial does not indicate zero when the current is connected, loosen the clamp screws on the generator or motor being set and turn its stator until both dials read zero; then tighten the clamp screws.

The stator of the generator is turned in the *opposite direction* to the rotor of the motor because the rotor of the generator is being held by gearing.



If the wires on the generator are secured and will not allow the stator to be turned far enough to zero the generator, unmesh the gears that drive the rotor. Turn the rotor of the generator until the standard motor dial reads zero.

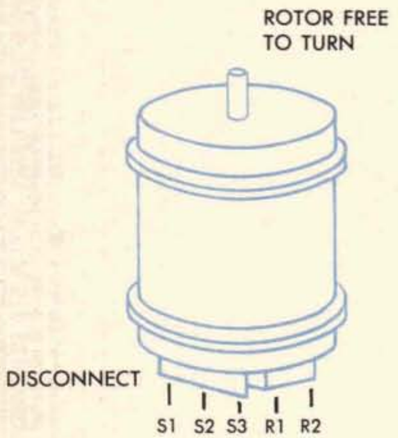


Remesh the gears to the nearest tooth.

Then if the dial is slightly off zero, loosen the clamps that hold the stator and turn the stator until the dial reads zero.

Tighten the clamps.

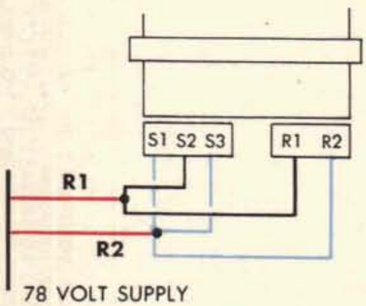
The ELECTRICAL LOCK METHOD



The Electrical Lock is another method of finding electrical zero.

First disconnect from the rest of the system the synchro motor or generator that is to be set.

Be sure the rotor is free to rotate.



Then connect *S2 to R1* and *S1 and S3 to R2* and put a 78-volt supply on the *R1* and *R2* leads.

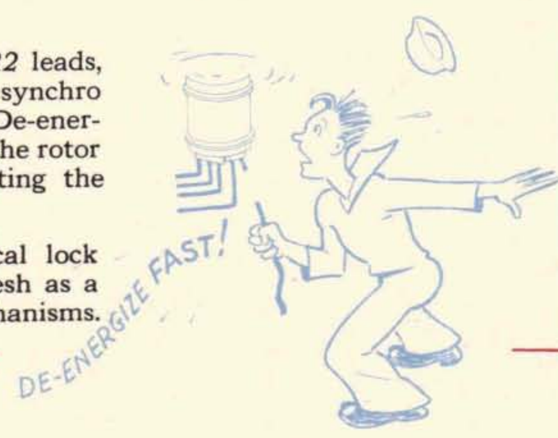
The rotor will snap around and the synchro will be *locked on electrical zero.*

Where a 78 volt supply is not available, a 115-volt supply may be used. It must be left on only for a few minutes—not longer than three or four, because the synchro may burn out if it remains on.

CAUTION:

When the power is supplied to the *R1* and *R2* leads, the rotor may whirl around very rapidly if the synchro is too far off electrical zero. This is dangerous. De-energize the synchro immediately and try to bring the rotor nearer to the zero position before reconnecting the power.

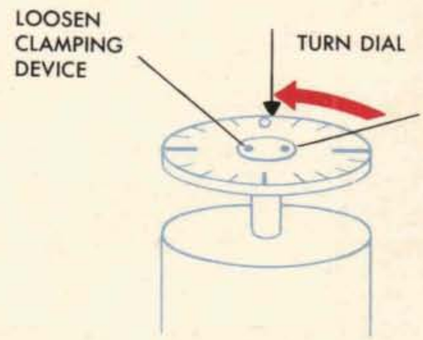
Before checking a generator by the electrical lock method, take the gear on the rotor out of mesh as a precaution against damaging gearing and mechanisms.



Resetting a dial

If the synchro is on zero but the dial is not, loosen the dial clamping device; then turn the dial until it reads zero. Tighten the clamping device.

There are several types of clamping devices. Find out how the dial is clamped, and use the proper tools.

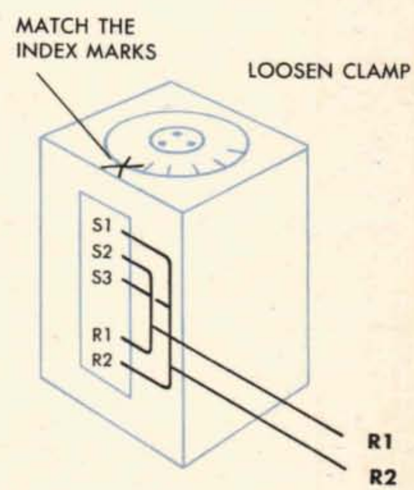


How to check the standard motor

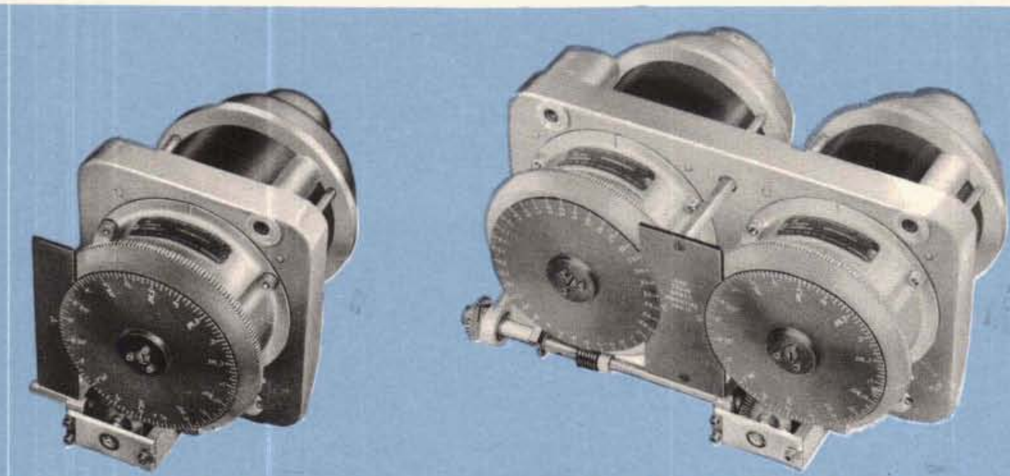
If there is any doubt about the accuracy of the standard motor, check it by the Electrical Lock Method.

When the standard motor is correctly set, the index marks will match whenever the leads are connected.

To correct the setting if the index marks do not match, loosen the dial clamp and turn the dial.



SYNCHRO TRANSMITTERS



SINGLE SPEED TRANSMITTER DOUBLE SPEED TRANSMITTER

SINGLE SPEED TRANSMISSION

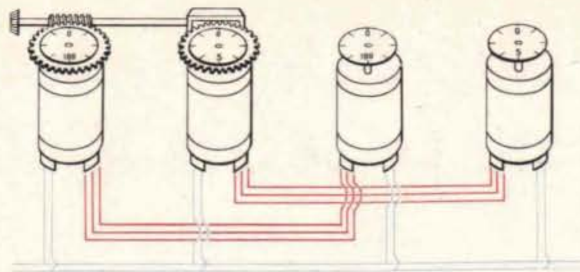
A single speed transmission system consists of a single generator transmitting a signal to single synchro motors as shown here. The single generator is known as a "single speed transmitter," and each synchro motor as a "single speed receiver." (In many cases, the synchro motor is used with a servo and a follow-up. This type of receiver is described in the next chapter.)

Bearing friction, because of the low torque at the synchronizing point, sometimes causes slight errors in the positioning of the motor rotor. Single speed transmission is sufficiently accurate to take care of the following kinds of quantities:

1 Quantities which do not have a definite reference, such as increments of generated range or bearing. When used to transmit such quantities, a single speed transmitter can be made as accurate as desired simply by gearing it to transmit a small value per revolution. If a change of range transmitter is geared to transmit 100 yards of range change per revolution, a $\frac{1}{2}°$ of error in the position of the motor rotor will result in a transmission error of less than 1 foot of range change.

2 Quantities having a small range of values, such as parallax corrections in the Computer Mark 1. Values of parallax corrections are only computed between $+12°$ and $-12°$ so that if one revolution of the generator rotor represents, say, $25°$ of parallax, an error as large as $\frac{1}{2}°$ in the position of the motor rotor will represent an error of only 2 minutes in the value which is being transmitted.

DOUBLE SPEED TRANSMISSION



This system consists of a pair of generators geared together and transmitting to one or more pairs of synchro motors. The "coarse" generator is usually worm driven and usually rotates once for either 18 or 36 revolutions of the "fine" generator.

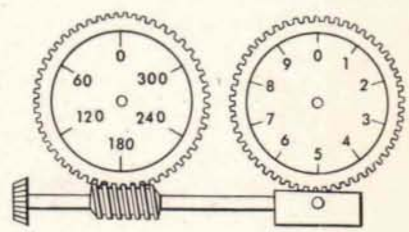
The two generators, geared together, are known as a "double speed transmitter," and the two synchro motors are known as a "double speed receiver." (In many cases, the synchro motors are used with a servo and a follow-up control. This is described later.)

Double Speed Transmission is used when very accurate transmission is necessary and the range of values to be transmitted is too great for accurate single speed transmission. An example of its use is the gun train order transmitter unit in the Computer Mark 1.

A dial on one generator has graduations from 0° to 360° so that one revolution of the dial equals 360° of bearing. This is the "coarse" dial.

The dial on the other generator has graduations from 0° to 10° so that one revolution of the dial equals 10° of bearing. This is the "fine" dial.

The gearing between the two generators is such that while the coarse dial is revolving once—the fine dial must turn 36 times.

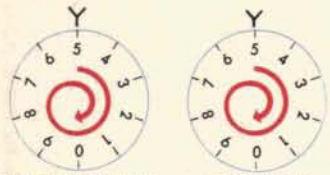


NOTE: The terms *single speed* and *double speed* when used with transmitters and receivers must not be confused with *one speed*, or *two speed* transmission.

When referring to transmission, *one speed* means that one revolution of a transmitter rotor represents the whole range of values concerned with that transmitter. For instance, one revolution of a rotor which represents 360° takes care of all values of bearing. A rotor representing 180° of bearing per revolution would have to be turned twice to transmit the full 360° of bearing, and therefore gives *two speed* transmission. A rotor representing 10° of bearing per revolution gives *36 speed* transmission.

The term *single speed* applies to a transmission system in which only one speed of transmission is used, while the term *double speed* denotes a transmission system in which two different speeds are used to obtain increased accuracy in transmitting an order. Thus a *single speed* system might transmit at 10 speed and a *double speed* system at 1 speed and 36 speed.

The FINE CONTROL cannot operate successfully alone



TRANSMITTER RECEIVER

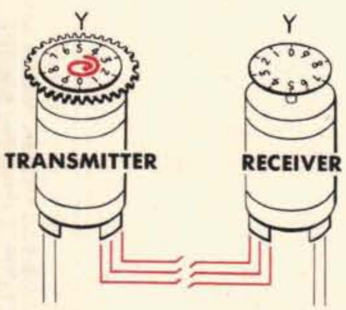
* IF FINE CONTROL ONLY WERE USED

At first glance, it might appear that a *fine* control system could take care of the whole operation of positioning a mechanism without assistance from a *coarse* control. But the coarse control plays two important roles:

1 Assume for a moment that a synchro team uses only the fine control principle, the transmitter and receiver dials being graduated from 0° to 10°.

If a value of 15° of Target Bearing is now cranked into the transmitter, the rotor of the fine motor will turn 1½ times, and the value 5 will appear opposite each index.

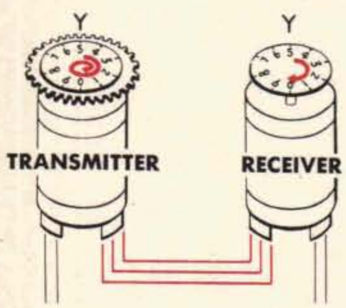
Since only the fine control is used, the same value 5 would appear if 5°, 15°, 25°, or 35°, etc., were cranked in.



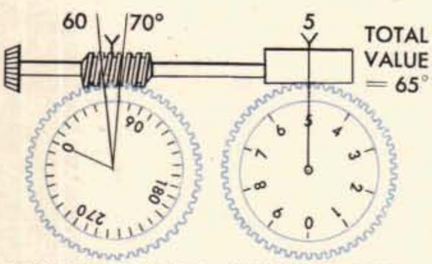
2 Suppose the leads between a single speed transmitter and receiver are disconnected, and the rotor of the transmitter generator is turned 1½ times, so that the graduation 5 comes opposite the index mark.

When the leads are again connected, the graduation 5 will come to the index of the receiver dial when the rotor of the synchro motor has made only ½ turn.

Although both transmitter and receiver dials now read 5°, the rotor of the receiver is one whole revolution (10°) out of synchronism with the transmitter.



It is impossible to read off total values transmitted from one fine dial to the other after one revolution has been made.



COARSE CONTROL FINE CONTROL

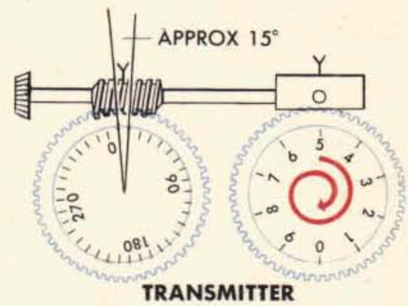
BOTH TRANSMITTER AND RECEIVER DIALS APPEAR LIKE THIS WHEN COARSE AND FINE CONTROLS ARE USED

By using the coarse control with the fine control, accurate total values can be read on the dials. The coarse control transmits a rough total value. Its dial is read to obtain the value transmitted by complete revolutions of the fine control.

The total value transmitted is read by adding the fine dial value to the value of the lower of the two graduations near the coarse dial index.

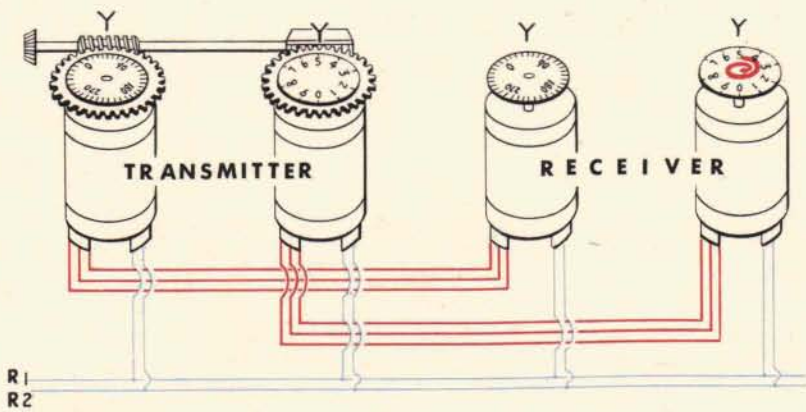
Use of the COARSE CONTROL synchronizes the receiver with the transmitter

Now assume that a coarse control is added to the fine—but the leads from the double speed transmitter to the receiver are not yet connected.



When a value of 15 is cranked into the double speed transmitter, dials of the coarse and fine generators appear as shown here (the fine dial having turned 1½ times).

When the circuit is completed the rotor of the coarse motor turns until its dial registers the same amount as the coarse generator, and the rotor of the fine motor turns until its dial reading conforms to that of the fine generator. *Readings taken from the two dials of the double speed receiver give the true total value of the signal transmitted.*



SUMMARY:

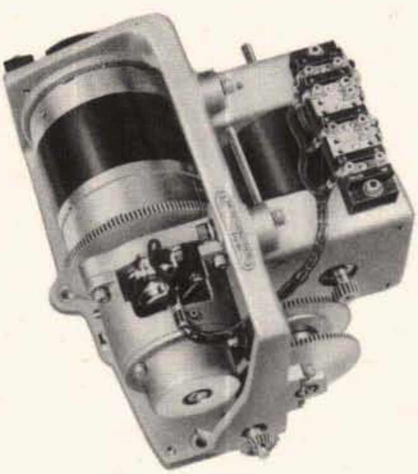
1 The coarse control keeps track of the number of revolutions the fine synchro turns.

2 The coarse control prevents the receiver from getting out of synchronism with the transmitter.

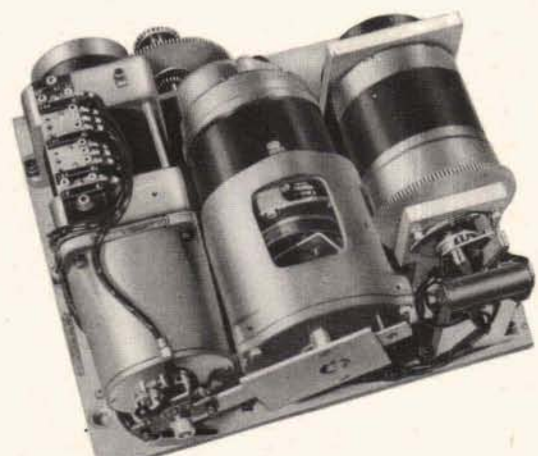
SYNCHRO RECEIVERS using servo motors

Although synchro motors transmit extremely accurate signals, their outputs must be "boosted" considerably before they can drive heavily loaded shafts. The reason is that the torque delivered by a synchro falls off sharply as the rotor approaches the "point of synchronism." As the rotor nears the point of zero error, the induced current in the stator coils is rapidly reduced, seriously affecting the ability of the synchro to drive a heavy load. At the point of zero error, torque becomes zero.

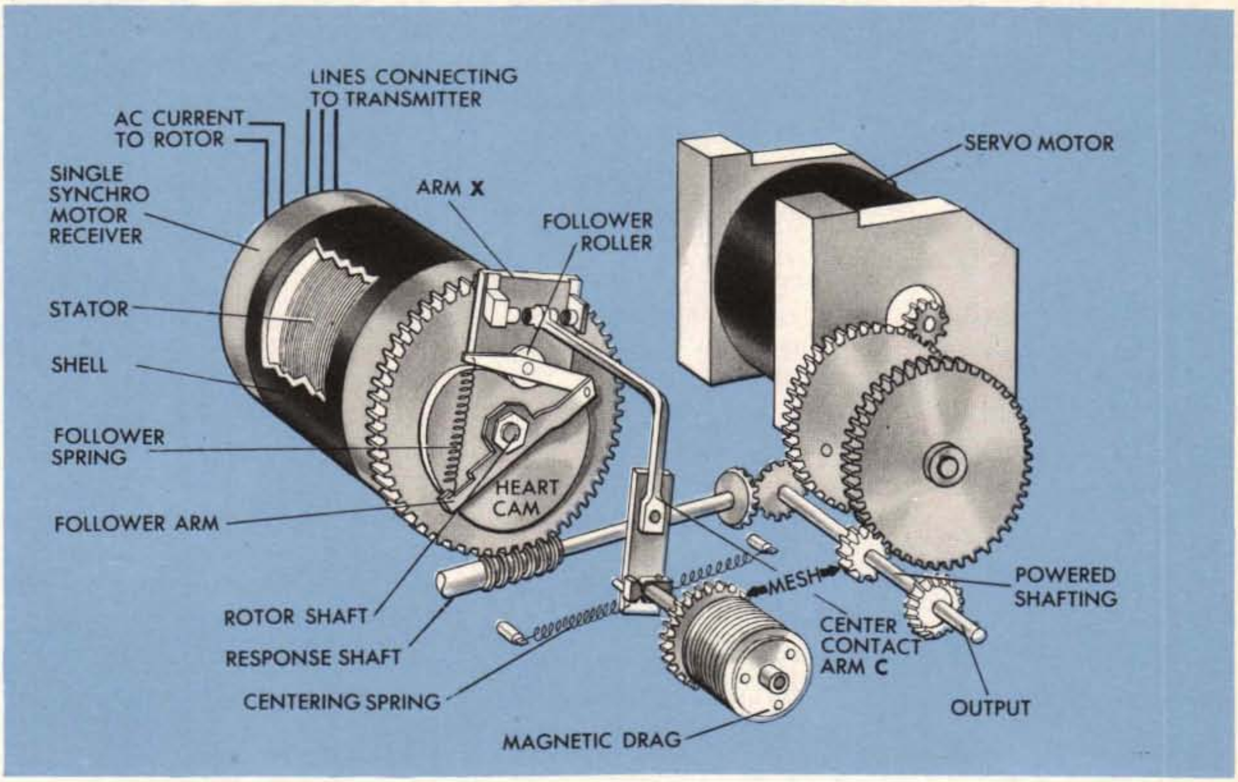
Accordingly, *synchro motors* are commonly used as *controls for servo motors* that drive the actual shaft load. Such synchro-servo combinations are known as Synchro Receivers. There are two types: single speed and double speed. The double speed unit provides fine and coarse control.



SINGLE SPEED RECEIVER WITH SERVO MOTOR



DOUBLE SPEED RECEIVER WITH SERVO MOTOR



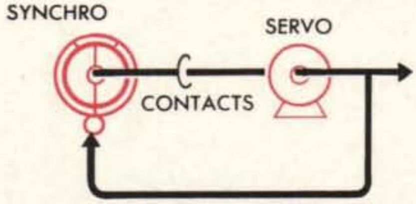
The SINGLE SPEED receiver

The contacts controlling the action of the servo are similar to those of a follow-up control.

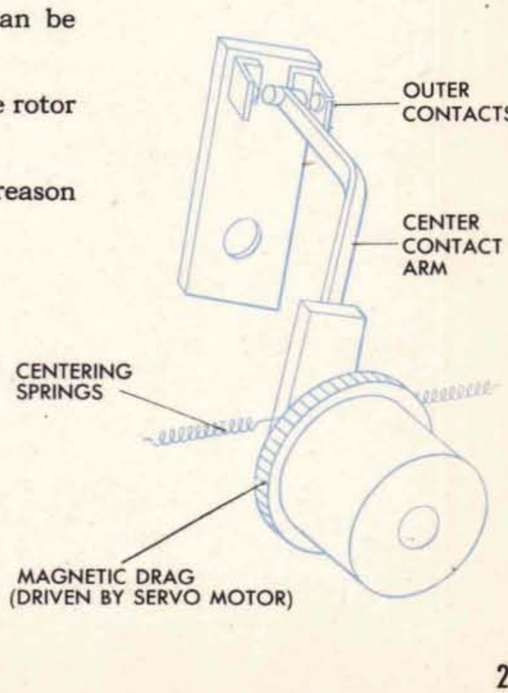
The two outer contacts are fixed on an arm which can be rotated.

The center contact is mounted on an arm attached to the rotor of a magnetic drag which is driven by the servo.

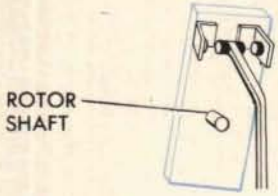
The drag is used here in the same way and for the same reason as in the usual follow-up.



THIS IS A SIMPLIFIED SCHEMATIC REPRESENTATION OF THE SINGLE SPEED RECEIVER

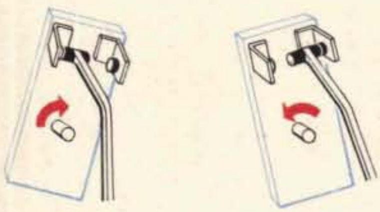


How the CONTACTS work



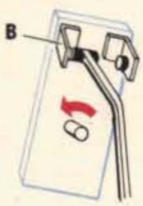
To understand how these contacts are controlled, first assume that the outer contact arm is fixed to the rotor shaft of the synchro motor.

Making the contact



Assume that the rotor has turned in response to a transmitted signal, until one outer contact or the other is brought against a center contact–depending upon the direction taken by the rotor.

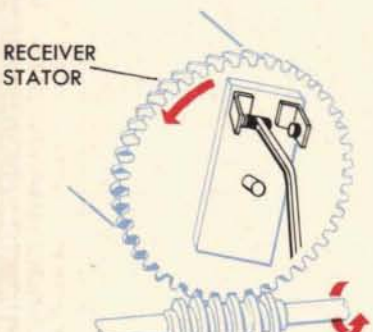
Breaking the contact



A way must now be found to separate the contacts once the servo has obeyed the signal. This can easily be accomplished by turning the rotor back in the direction from which it started.

For example, if the rotor were turned so as to make an electrical connection with the outer contact *B,* it would have to be turned back as indicated by the red arrow in order to break the contact.

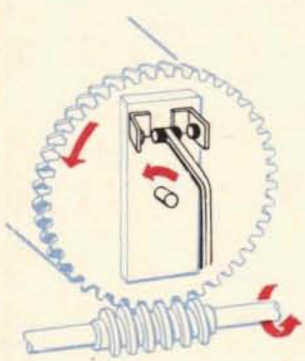
Why the Stator is turned



Since the rotor has been positioned in accordance with the transmitted signal, a means must be found to turn the rotor back without altering the signal value.

But the rotor of a synchro always tends to maintain its position relative to the receiver stator coils, no matter how much the stator may be rotated. The rotor may be turned back as much as necessary, without disturbing the signal value, *simply by rotating the stator.*

Turning the stator

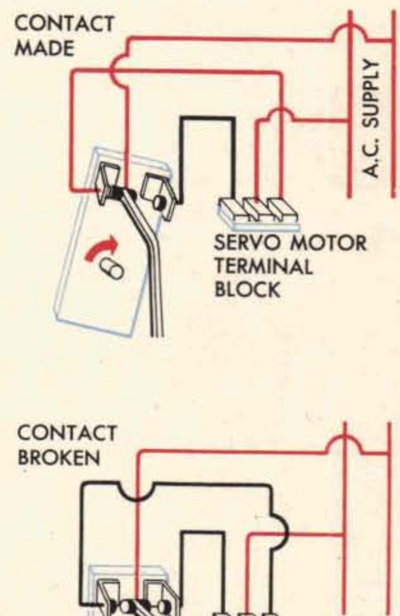


The motor stator, therefore, is geared to the "response" shaft of the servo, and the whole stator is rotated in the opposite direction to that taken by the rotor.

This means that AS THE STATOR OF THE SYNCHRO MOTOR IS ROTATED BACK, THE ROTOR, KEEPING ITS POSITION IN RELATION TO THE STATOR, IS ROTATED BACK ALSO. IN THIS WAY, THE OUTER CONTACT ARM IS BROUGHT BACK TO ITS CENTER POSITION WITHOUT DISTURBING THE POSITION OF THE ROTOR IN RELATION TO THE STATOR.

The receiver is like a FOLLOW-UP

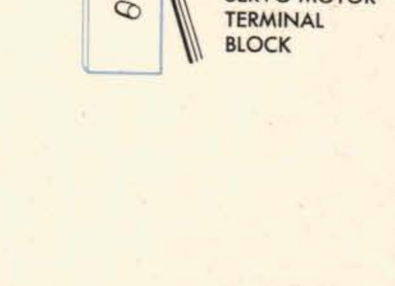
The Synchro Receiver, then, is a device which can operate like a follow-up control. In fact, it is often referred to as a "synchro follow-up."



Why the servo drives

When the rotor of the synchro motor revolves, contact is made between an outer and the center contact, and the servo drives.

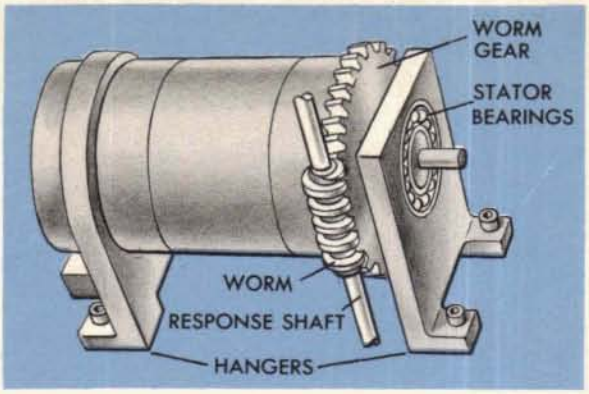
When the synchro stator is rotated back by the servo response, the contacts are separated and the servo ceases to drive.



Special connections are needed

When a synchro stator must be rotated, a "Bearing-mounted Synchro Motor" is used. This type of synchro motor is provided with a slip ring and brush assembly to transfer the electrical circuits from the stationary frame to the rotating synchro motor.

The BEARING-MOUNTED SYNCHRO MOTOR

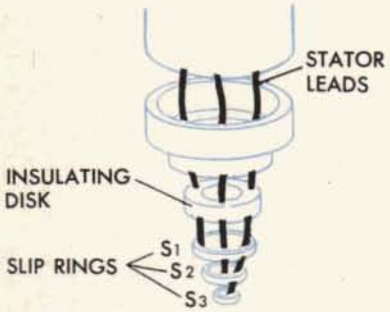


The rotor and stator are mounted so that both can turn

The synchro motor, with its stator bearings, is mounted in hangers.

The rotor is positioned by a signal from the transmitter. The stator is turned by a worm and worm gear, driven by the servo response.

The stator leads pass through the one end cap, then through an insulating disk, and finally to the slip rings *S1*, *S2*, and *S3*, where they are secured. When the end cap is assembled, the slip rings are fastened to the insulating disk, and the disk to the end cap. The rotor leads are connected to two slip rings on one end of the rotor shaft.



One brush contacts each slip ring

Three brushes, marked *S1*, *S2*, and *S3*, bear against the stator's slip rings. Two brushes, *R1* and *R2*, bear against the slip rings on the rotor shaft. All five brushes are mounted on a terminal block and so connected that signals can be transmitted to the receiver on the three stator leads while leaving the stator at all times free to turn. 115-volt A.C. can be fed to the rotor in the usual way without interfering with the stator's freedom to turn. The terminal block and brush assembly are mounted on the stationary hanger.

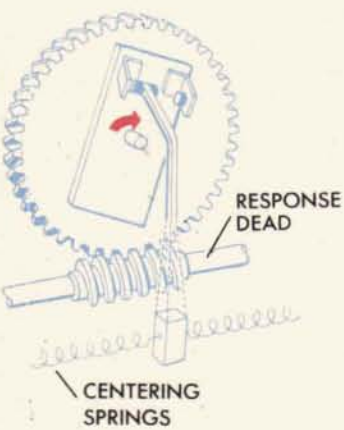
The purpose of the heart cam

Suppose that a signal causes the rotor of the synchro motor to turn *while the power to the servo* is shut off.

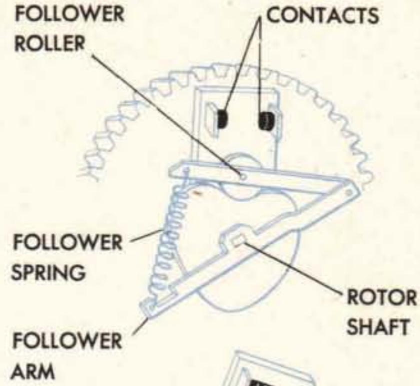
In this case, contact would be made between an outer and a center contact, but would not be broken (for the servo's response is dead).

The synchro rotor would turn, rotating the outer contact arm against the center contact arm, and possibly damaging the contacts.

To prevent this, the arm carrying the outer contacts is *not* attached directly to the rotor shaft, but is fixed to a "heart cam." This heart cam is ball-bearing-mounted on the rotor shaft, so that it can turn freely.

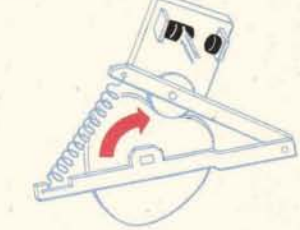


The CAM at work



A follower arm, with a follower roller and a spring, is keyed to the end of the synchro motor's rotor shaft. The spring keeps the follower roller seated firmly in the "valley" of the heart cam.

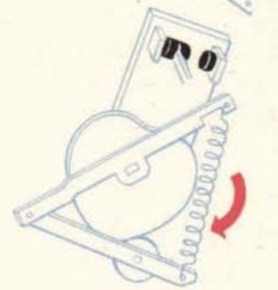
Whenever the rotor is turned by an incoming signal, the follower arm must turn, because it is keyed to the rotor shaft. As the follower arm turns, the follower roller is pulled around. The roller, being firmly seated in the valley of the cam, pulls the cam around. When the cam is rotated, an outer contact is brought against the center contact, and the servo starts to drive.



The rotor can continue turning after the contact is made

As the signal continues to come in from the transmitter faster than the servo can drive, the rotor of the synchro motor continues to turn and carry the follower arm around with it. The follower roller is now forced up and out of the valley, and rides around the heart cam (pressed to the side of the cam by the action of the spring).

So although an outer contact is now held firmly against the center contact, *the rotor is still free to turn.*

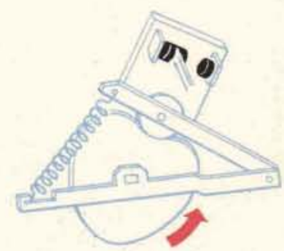


Now the rotor can turn until the follower roller reaches the peak of the cam *without disturbing the contacts.*

This means that if the servo power is shut off, a considerable input can be transmitted to the synchro receiver without throwing the system out of synchronism. In other words, the heart cam carries out the job performed by the intermittent gearing in other types of follow-up controls.

If the follower roller goes over the peak of the cam, the receiver will be out of synchronism with the input and will have to be re-set.

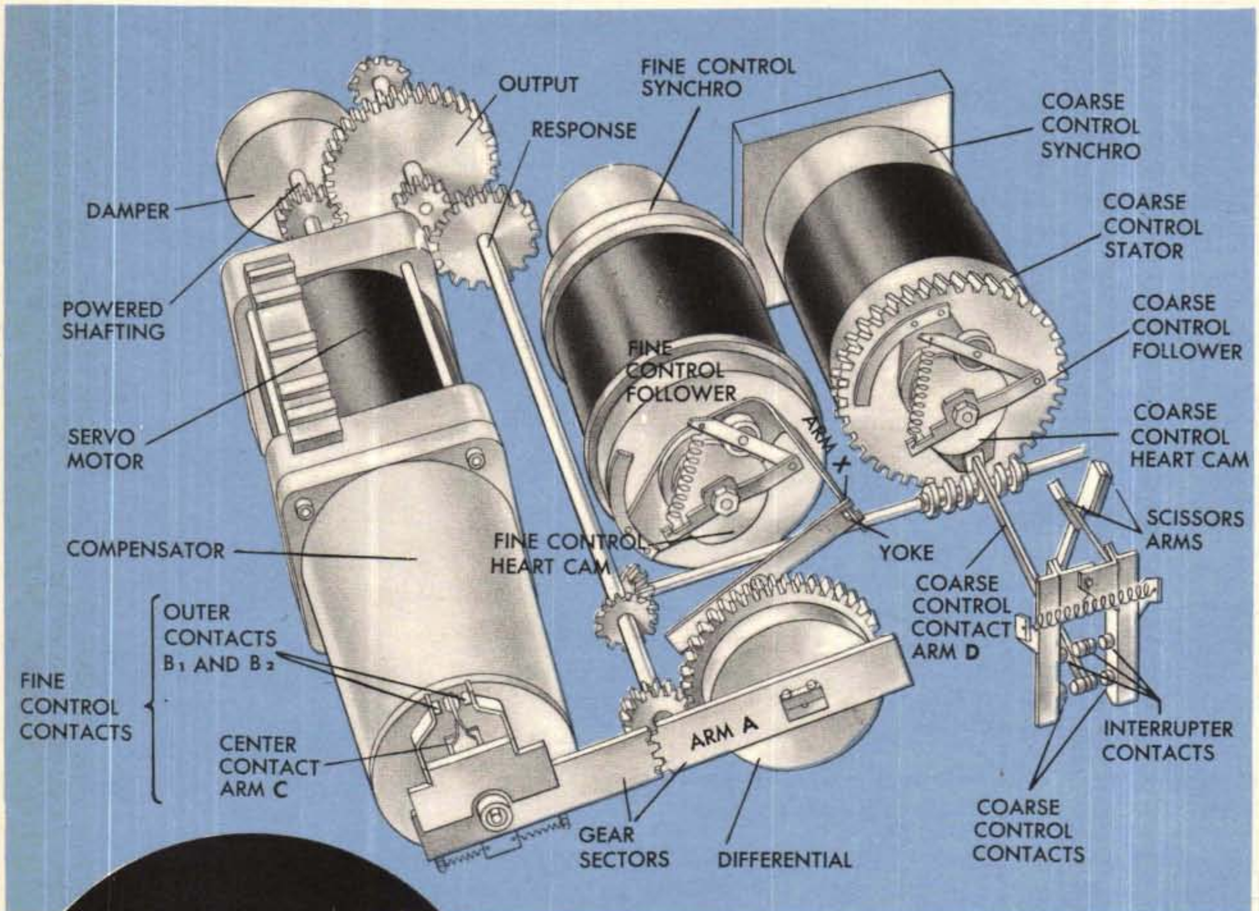
The rotor stays in the correct relationship to the stator

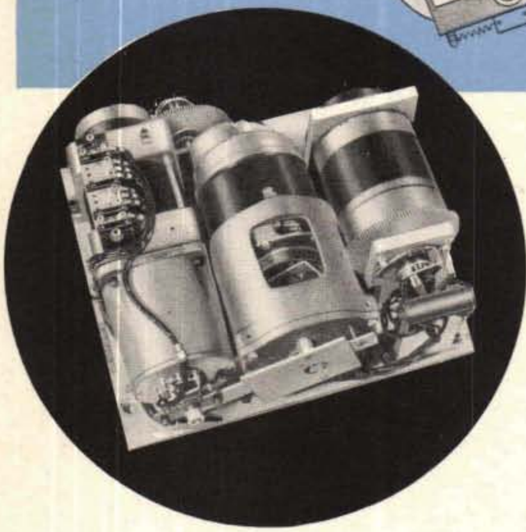


When the stator of the synchro motor is rotated, the rotor is turned back toward the position from which it started, and the follower roller becomes again seated firmly in the valley of the heart cam through action of the follower spring. The contacts are not yet separated, so the servo keeps driving the stator around.

As the rotor is turned still farther, the heart cam is moved around by the follower arm. The contacts separate, and the servo ceases to drive.

The DOUBLE SPEED receiver





In the double speed receiver, two synchro motors are used. One of these is connected to the coarse generator, and the other to the fine generator of a double speed transmitter.

Each synchro motor operates contacts which can control the action of the receiver's servo motor.

The fine and coarse synchro motors, however, cannot control the servo at the same time (except for a small interval when the coarse is taking over complete control from the fine). When the coarse synchro motor is in control, the contacts of an "interrupter," mounted on the scissors arms, are separated. Separation of the interrupter contacts breaks the circuit connecting the fine control contacts to the servo.

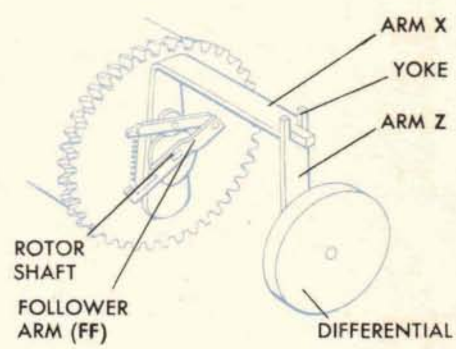
Normally, whenever the receiver is following a signal, the fine synchro motor controls the servo motor. If, for any reason, the output of the receiver is considerably out of synchronism with the input signal, the coarse synchro motor takes over control of the servo. The servo then drives, under coarse control, until the fine response (Arm X) is within approximately 1/3 of a revolution of its synchronized position.

In most double speed receivers the fine synchro rotor has a value per revolution of 10°. The coarse synchro takes control only when the output is more than about 3° (1/3 of a revolution) out of synchronism with the input signal.

How the FINE control operates

Upon receiving a signal from the transmitter, the fine control rotor turns.

The follower arm, *FF*, which is keyed to this rotor, also rotates.



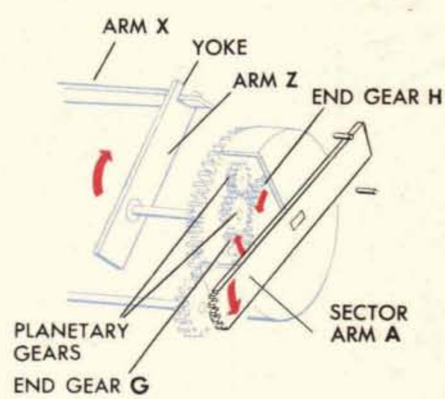
Behind the follower is the heart cam, ball bearing mounted and free to turn on the rotor shaft. The metal arm, *X*, is fixed to the heart cam.

As the follower arm rotates, with the follower roller firmly seated in the valley of the cam under spring pressure, it pulls the cam around with it.

Arm *X* fits into a yoke in arm *Z*.

As arm *X* rotates, it rotates arm *Z*.

Arm *Z* is connected to end gear *G* of the differential. As *Z* rotates, it turns this gear.

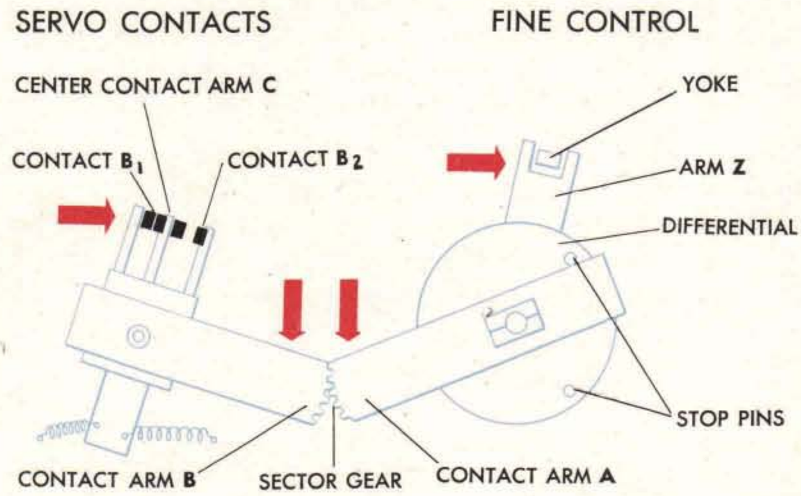


As gear *G* rotates, through the planetary gears of the differential, it rotates the other end gear, *H*.

End gear *H* is connected to sector arm *A*. As gear *H* rotates, arm *A* rotates.

In this way, the rotation of the fine synchro rotor causes arm *A* to rotate.

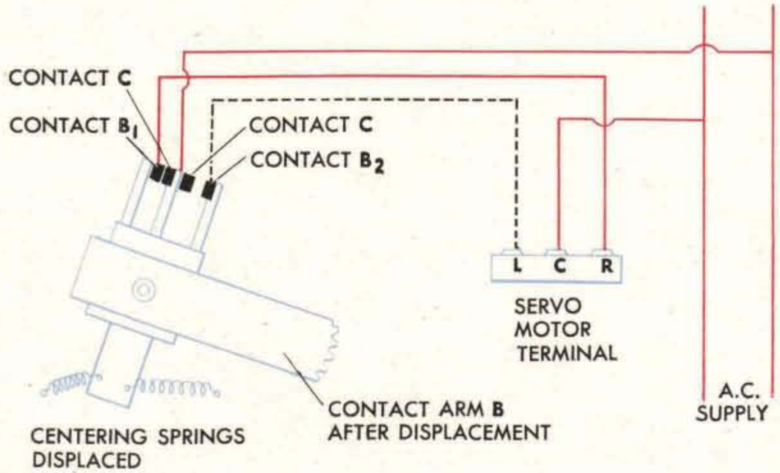
How the FINE control operates (continued)



Arm *A* will move until it closes the contacts. The stop pins limit the rotation of arm *A* and so prevent it from moving out of mesh with arm *B*.

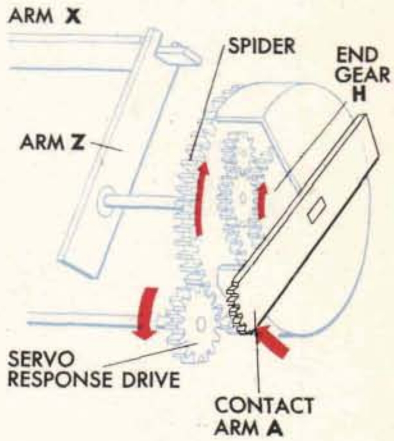
As arm *A* rotates, contact arm *B* is moved from its center position. This brings one of the outer contacts, *B1* or *B2*, mounted on arm *B*, against the center contact.

Closing the contacts completes a circuit to the servo motor, and the servo drives.



If contact is made between *B1* and *C*, the servo drives in one direction. If contact is made between *B2* and *C*, it drives in the opposite direction.

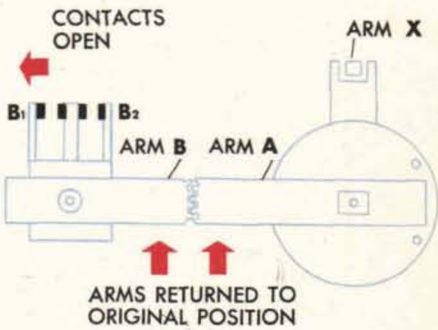
The servo motor is geared to the spider of the differential so that when the servo drives, the spider of the differential is rotated. This rotation causes the differential end gear *H* to turn in a direction which tends to move arm *A* back to its original or synchronized position.



The position of arm *A* at any instant corresponds to the difference, or "error," between the output of the fine control receiver and the output of the servo. When the point of synchronism is reached, there is no error. Contact arm *A* is back again in its original position, centered between the stop pins. This means that the contacts are separated, and the servo ceases to drive.

Here's a quick run through the fine control

1. The rotor of the fine synchro motor turns and rotates arm *A*. This displaces contact arm *B*, and contact is made between an outer and an inner contact.
2. The servo drives the output shafting, which positions whatever computer mechanism is involved, and also rotates the spider of the differential.
3. Rotation of the differential spider rotates arm *A away* from the stop pin, back towards the position from which it started.
4. When the output of the servo motor equals the output of the fine control synchro, arm *A* is again back in its original position, centered between the stop pins.
5. Now the contacts are separated, and the servo stops driving.



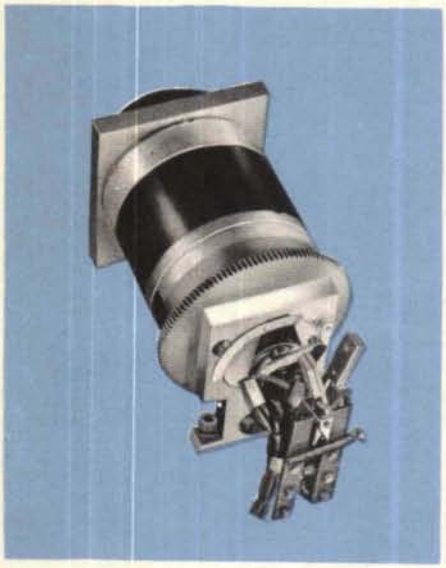
NOTE: When the coarse synchro motor is in control, contacts *B1* and *B2* will also close and open, but their movement will have no effect upon the action of the servo.

When the coarse synchro motor is controlling the servo, the response shaft, being geared to the servo, continues to drive the spider of the differential. This means that the response "backs out" through the differential and causes arm *X*, on the fine control synchro, to be rotated. When this occurs, the contacts of the fine control (*B1* and *B2*) are closed and opened according to the direction in which arm *X* is rotated.

However, when the coarse synchro is in control, the fine control circuit is broken at the interrupter, and no current can flow to the fine contacts.

The closing and opening of these contacts, therefore, has no effect upon the action of the servo.

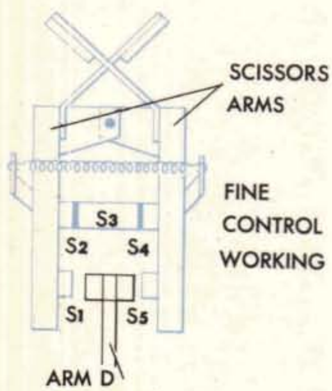
The COARSE control operation



The coarse control does two jobs.

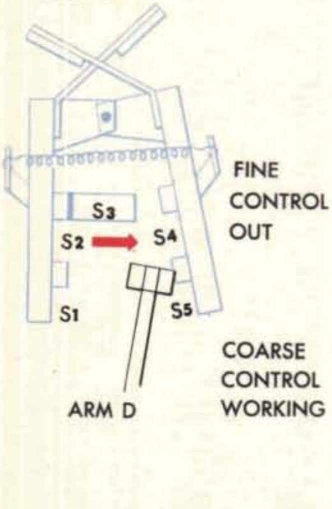
1 By opening the interrupter contacts it takes control away from the fine control contacts. It does this whenever the error between the signal and the response becomes too large for the fine control to handle.

2 By positioning the coarse contacts it then controls the servo motor. The servo motor drives to reduce the error between the signal and the output. When the error is reduced the interrupter contacts close and the fine control contacts take control.



A close-up of the contacts

Contact arm *D* and the scissors arms form a double pole switch. Contact arm *D* is positioned by the coarse synchro rotor through the heart cam. When the scissors arms are in their normal position, contacts *S2, S3, and S4* of the interrupter are closed. This completes the fine control synchro circuit to the servo motor. Contact *S3* is fixed and insulated from the frame.



When contact arm *D* is rotated against contact *S5*, the pressure exerted by arm *D* displaces one scissors arm, and the contacts *S3* and *S4* are separated, breaking the circuit through which the fine control synchro motor controls the servo.

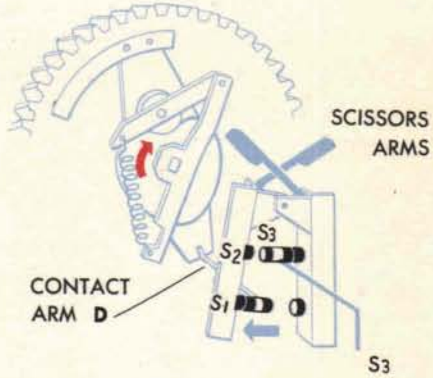
But as contact arm *D* presses against *S5*, another circuit to the servo is completed. Through this new circuit the *coarse* synchro motor controls the servo motor.

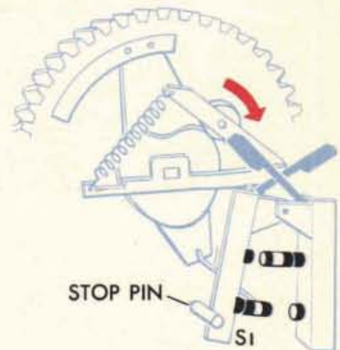
The coarse synchro takes over control. The fine control synchro is automatically cut out. When the contact is made between arm *D* and contact *S1*, the servo motor is driven in the opposite direction by the *coarse* control synchro, and the fine control circuit is broken by the separation of *S2* and *S3*.

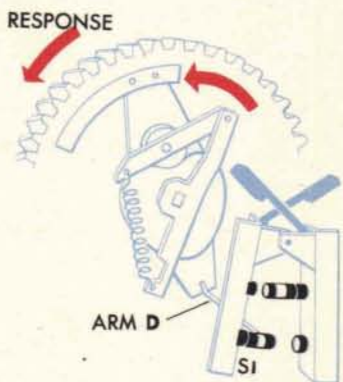
How coarse control works

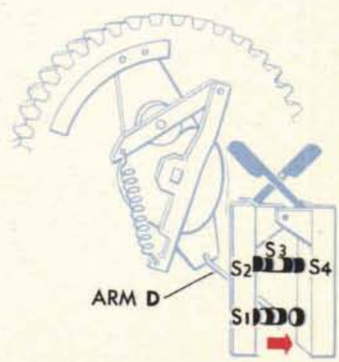
If the receiver is out of synchronism with the transmitter by a considerable amount the following action takes place:

1. When a signal is received from the transmitter, the coarse control rotor is rotated.
2. The heart cam, ball-bearing-mounted and free to turn on the rotor shaft, is pulled around by the follower, with the roller in the valley of the cam.
3. Contact arm *D*, being fixed to the heart cam, is rotated and brought against *S1*, on a scissors arm.
4. This starts the servo.
5. As contact arm *D* is brought against *S1* the scissors arm to which *S1* is fixed is displaced, and contacts *S2* and *S3* are separated.
6. When *S2* and *S3* are separated, the fine synchro takes no part in the control.
7. After the scissors arm is displaced a short distance, it comes against a stop pin.
8. But the rotor of the coarse synchro motor continues to rotate in accordance with the signal.
9. The heart cam follower, being keyed to the rotor shaft, continues to turn with the rotor, and the follower roller is forced up and out of the valley of the cam and rides down the slope of the cam. The scissors arm remains displaced.
10. The stator of the coarse synchro motor is rotated by the servo response shaft, in the opposite direction to that taken by the rotor.
11. The rotor, keeping its position with respect to the stator, is brought back until the roller is once more seated in the valley of the heart cam.
12. However, contact arm *D* is still pressed against *S1*.
13. The servo continues to drive and rotate the stator of the coarse synchro motor until contact arm *D* is separated from *S1*, and the circuit operated by the coarse control synchro is broken.
14. As contact arm *D* separates from *S1*, the contacts *S2* and *S3* are held together by the spring between the scissors arms—completing the circuit which gives control to the fine synchro motor. Contact arm *D* of the coarse motor always breaks the circuit through *S3* before the rotor of the fine control synchro motor has turned sufficiently to cause the follower roller to be driven over the peak of the fine heart cam. In this way the coarse control keeps the mechanism from getting out of synchronism with the generators of the transmitter.

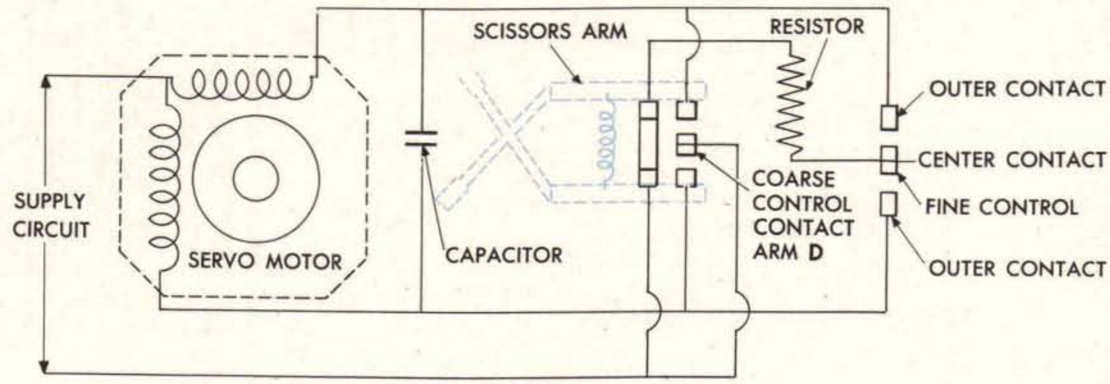




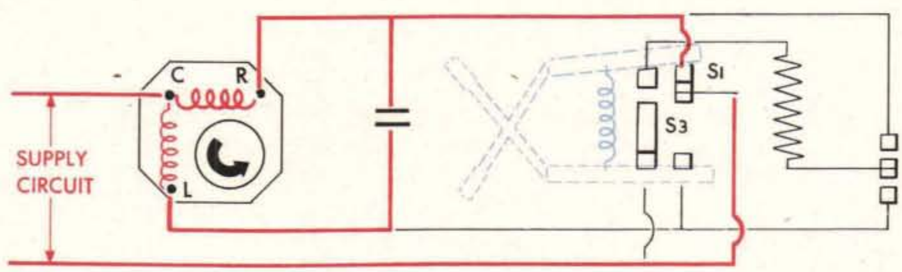




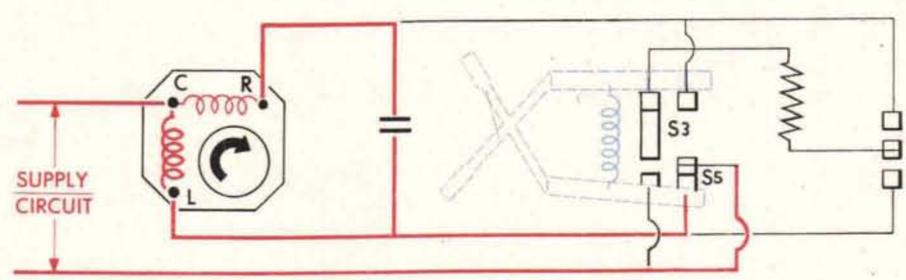
WIRING DIAGRAM



Here is the wiring for the double-speed receiver. Neither the coarse control nor the fine control is shown in operation; the servo motor is at rest.

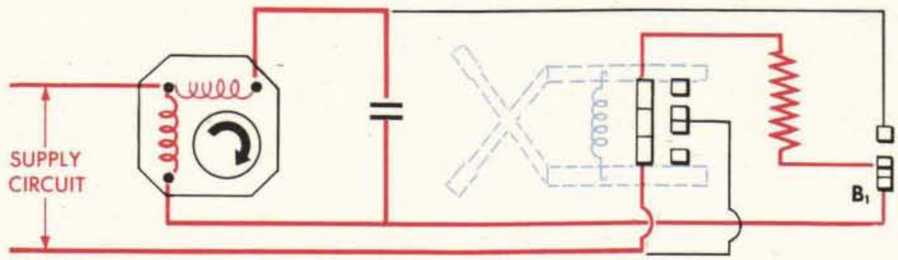


When the contact arm of the coarse synchro motor is rotated against *S1* on the scissors arm, fine control contacts are eliminated, because the circuit through *S3* is broken, and the servo drives in one direction.

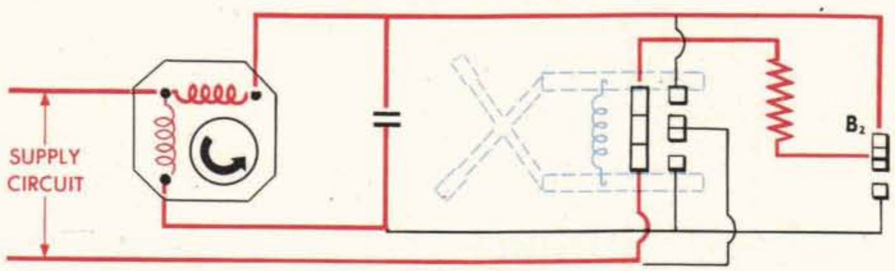


When the contact arm of the coarse synchro motor is rotated against *S5* on the scissors arm, fine control contacts are also eliminated, because the circuit through *S3* is broken, and the servo drives in the opposite direction.

for the double speed receiver

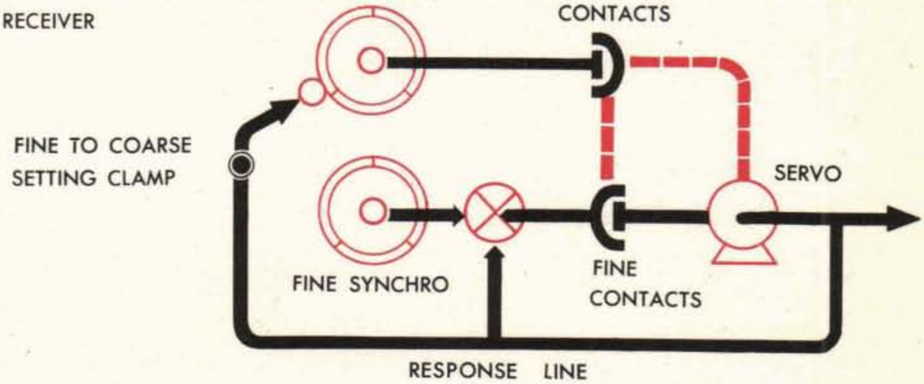


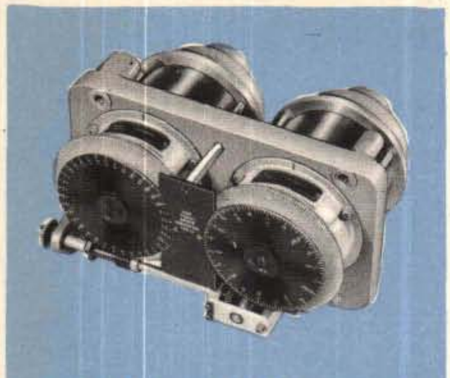
When the contact arm of the coarse control synchro motor is centered, and outer contact *B1* is brought against the center contact arm by the fine control synchro motor, the servo drives as indicated.



When the contact arm of the coarse control synchro motor is centered, and outer contact *B2* is brought against the center contact arm by the coarse control synchro motor, the servo drives in the opposite direction.

THIS IS A SIMPLIFIED SCHEMATIC REPRESENTATION OF THE DOUBLE SPEED RECEIVER





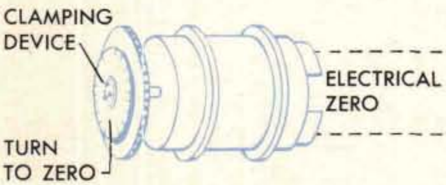
DOUBLE SPEED TRANSMITTER

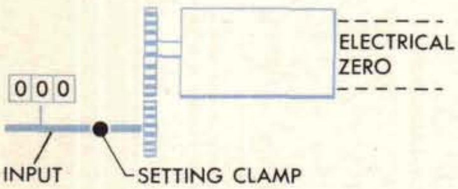
Setting TRANSMITTERS

A *transmitter* is a synchro unit having a mechanical input and electrical output; a *receiver* is a synchro unit having an electrical input and a mechanical output.

The purpose when setting is to join the inputs and the outputs so that the electrical and mechanical systems are in agreement.

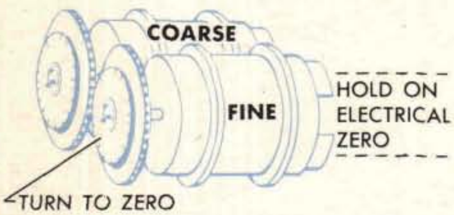
This agreement is reached by using the electrical zero position of the synchro as the reference point when joining the electrical and mechanical signals.

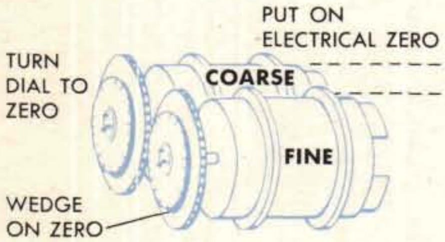


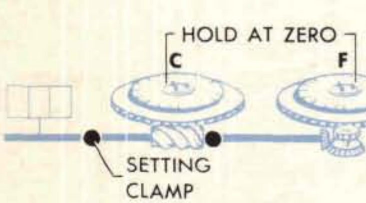


To set a **SINGLE** SPEED TRANSMITTER

1. Put the synchro transmitter on electrical zero.
2. Turn the dial of the synchro transmitter until it reads zero.
3. Tighten dial clamping device.
4. Holding the synchro transmitter dial at zero, put the input counter on zero.
5. Tighten the setting clamp.
6. Disconnect all test wires.



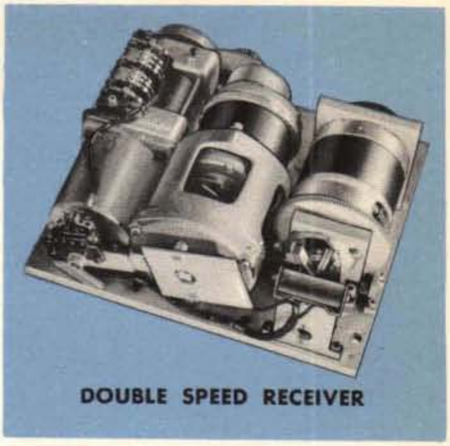




To set a **DOUBLE** SPEED TRANSMITTER

1. Put the FINE transmitter on electrical zero.
2. Holding the FINE transmitter on electrical zero, turn its dial until it reads zero.
3. Tighten the dial clamping device.
4. Wedging the FINE dial at zero, put the COARSE transmitter on electrical zero.
5. Holding the COARSE transmitter at electrical zero, turn its dial to zero.
6. Tighten the dial clamping device.
7. Tighten the clamp controlling the FINE to COARSE setting.
8. Holding both transmitters at their zero positions, turn the input counter until it reads zero.
9. Tighten the setting clamp.
10. Remove the wedge.
11. Disconnect all test wires.

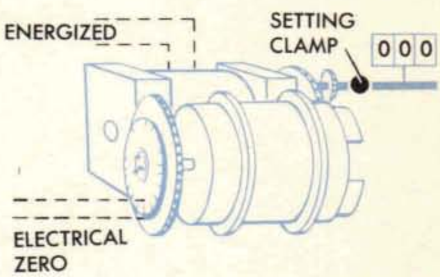
and RECEIVERS



DOUBLE SPEED RECEIVER

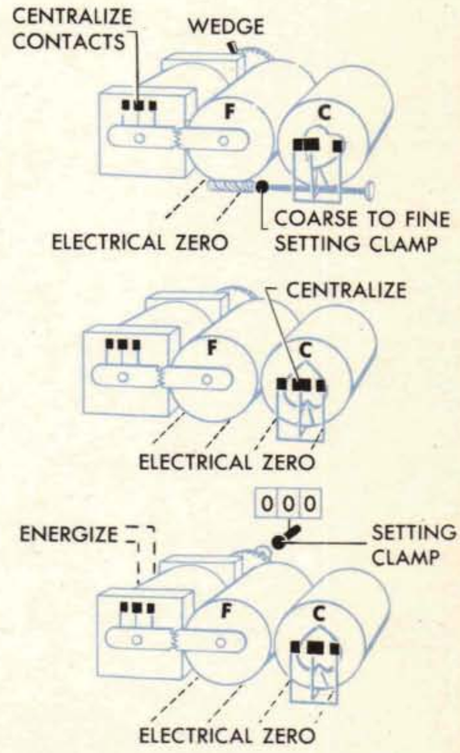
To set a SINGLE SPEED RECEIVER

1 With the synchro motor on electrical zero, energize the servo motor. It will synchronize at zero.
2 Turn the output counter until it reads zero.
3 Tighten the setting clamp.
4 Disconnect all test wires.



To set a DOUBLE SPEED RECEIVER

1 Put the FINE synchro motor on electrical zero.
2 With the FINE synchro on electrical zero, turn the motor shafting to centralize the FINE contacts.
3 Wedge the motor shafting at its zero position.
4 With the COARSE synchro on electrical zero, centralize the COARSE contacts by slipping the worm on the shaft driving the coarse synchro.
5 Tighten the clamp controlling the COARSE to FINE setting. This clamp is on the worm gear.
6 Remove the wedge from the shafting.
7 Energize the servo motor. It will synchronize at zero.
8 With both synchros on electrical zero and the servo motor energized, turn the output counter until it reads zero.
9 Tighten the setting clamp.
10 Disconnect all test wires.



SECTION 4

SUMMARY: A SIMPLIFIED NETWORK

Now that all of the basic mechanisms have been described individually, it is time to see, in a general way, how they work together to solve a fire control problem.

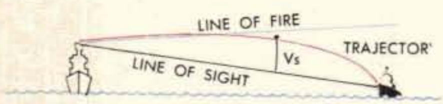
In order to avoid the complexities of any actual computer, Section 4 shows how an imaginary, simplified network of mechanisms might be put together. This network is sufficiently similar to the networks in actual computers to show how mechanisms can be connected to solve mathematical problems mechanically.

The imaginary network is also sufficiently realistic to demonstrate the general procedures for setting any network of mechanisms.

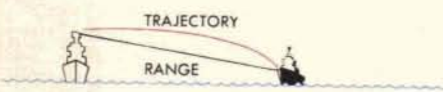
A SIMPLIFIED NETWORK

Each basic mechanism in a computer does one particular job. These mechanisms are combined into networks. Each network solves mathematical equations to arrive at a value that is needed in solving the fire control problem.

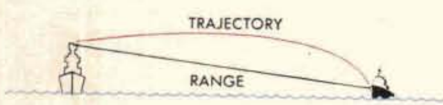
In this section an imaginary simplified network is described in order to show how the basic mechanisms are combined into computing networks and how such networks are set. This simplified network is not taken from any actual instrument but was made up specially for this section in order that certain principles could be shown more easily.



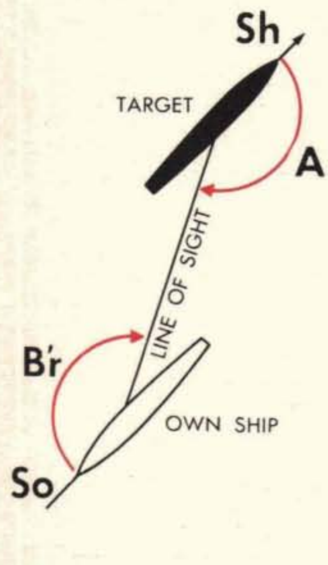
The network roughly approximates a solution of part of the fire control problem for a surface target. It finds Sight Angle, Vs, the amount that the guns must be elevated above the Line of Sight to allow for the drop of the shell. This drop is greater for long ranges, which makes it necessary for the guns to be elevated more for long ranges than for short ranges.



Since the range is changing as the ship and target move, and since the shell takes an appreciable time to reach the target, the value of sight angle used in firing the guns must be chosen for the value of range at the end of the time of flight of the shell, that is, Advance Range.



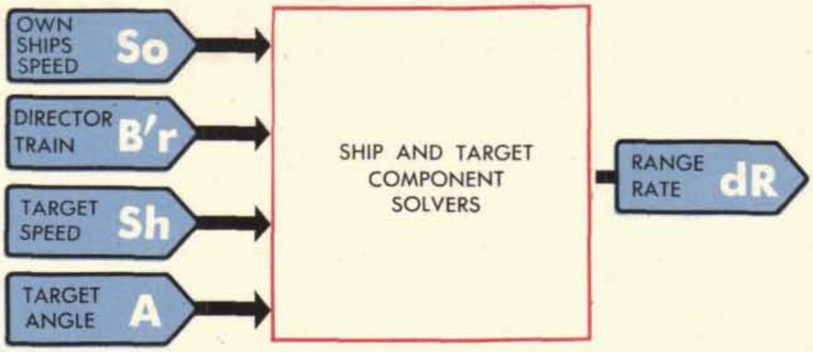
Advance Range in this problem is the sum of the Present Range and the predicted change in Range caused by relative motion between Own Ship and the Target, during time of flight of the shell.



In order to find Sight Angle, Vs, these six quantities are used as inputs to the network:

1. Own Ship Speed, So, which is assumed to come in automatically from a pitometer log, by synchro transmission.
2. Director Train, $B'r$, which could come in automatically from a director, also by synchro transmission.
3. Target Speed, Sh, which might be estimated at the director and be phoned down to the Computer and set in by hand.
4. Target Angle, A, which might also be estimated at the director and be phoned to the Computer and set in by hand.
5. Initial Range setting, jR, which could be phoned down from the Director and set into the Computer by hand.
6. Time, T, which is put in automatically by the time motor.

Component solvers figure RANGE RATE

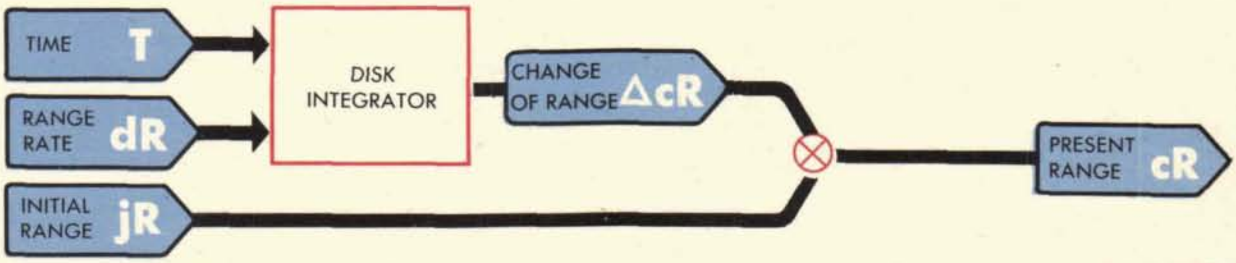


The first thing to do is to find out the rate at which the range between own ship and target is changing. This depends on the speed of both ships and their direction of travel in relation to the line of sight.

Own Ship Speed, Director Train, Target Speed, and Target Angle, are inputs to two component solvers.

The sum of the components of Ship Speed and Target Speed *along* the Line of Sight is the Range Rate, *dR*. Range Rate is the *rate* at which Present Range is changing.

An integrator finds PRESENT RANGE

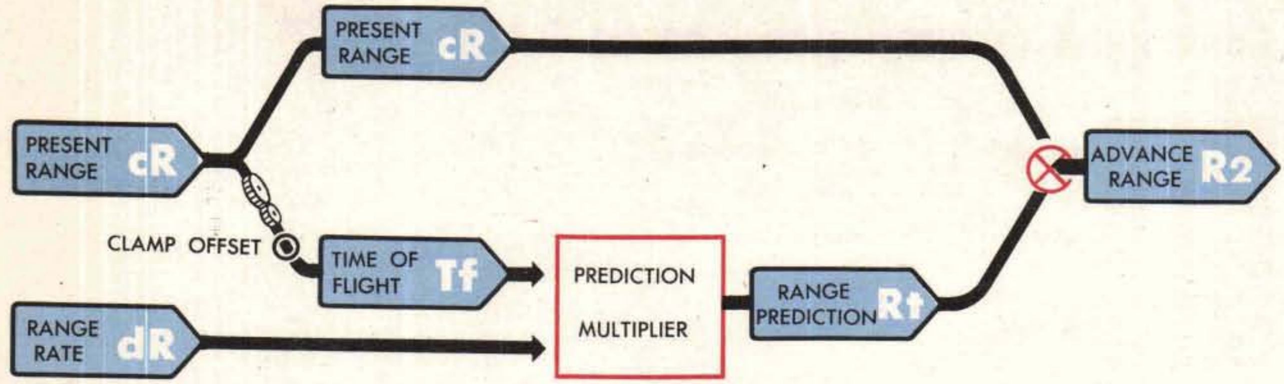


Range Rate, *dR*, now becomes an input to a disk integrator, together with Time, *T*, from the time motor.

The Time Motor drives the disk at a constant speed, and *dR* positions the carriage to control the speed of the output roller. The output drives one side of a differential in the range line and changes the value of Range in the machine as the actual range between the Ship and Target changes.

At any time after the start of the problem, the output of the integrator will have turned an amount corresponding to the amount that Range has changed since the problem started. The output of the integrator is referred to as "Generated Changes of Range," $\triangle cR$. Generated Changes of Range, $\triangle cR$, are continuously added in a differential to Initial Range Setting, *jR*, to give the computed Present Range, *cR*, at every moment.

PRESENT RANGE



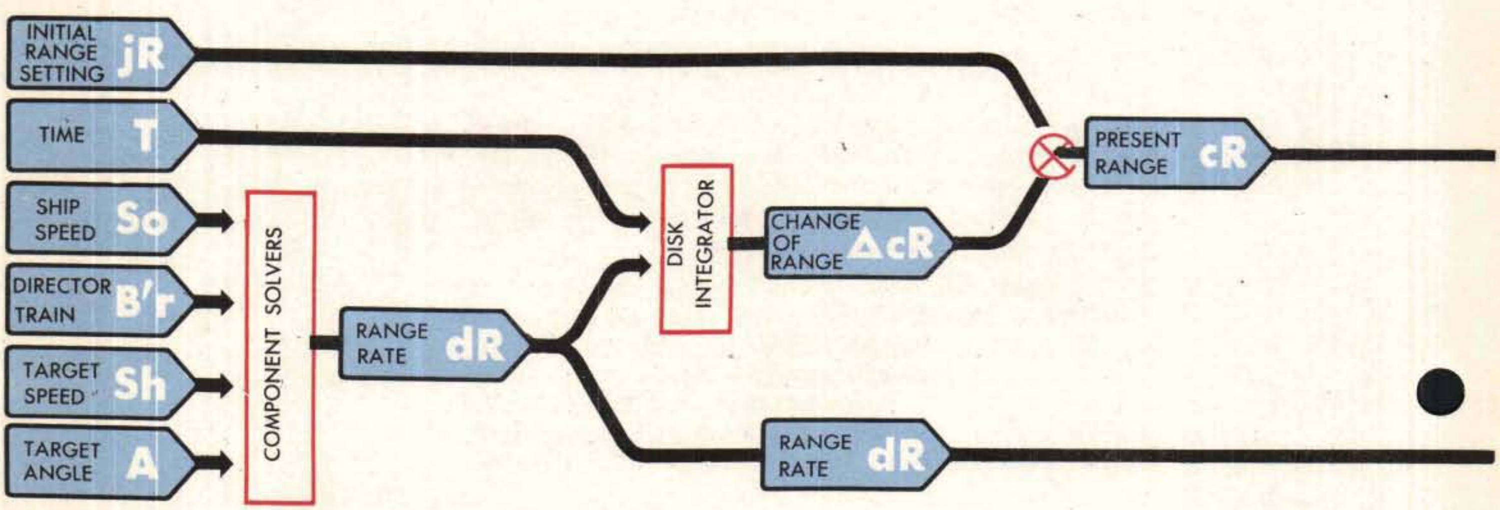
If Present Range, *cR,* were used for firing the guns, the shell would not hit the target because the Target and Own Ship are moving while the shell is in flight. This change in range during the time of flight is Range Prediction, *Rt.*

In order to simplify this network, it has been assumed that there is a fairly constant ratio between range and time of flight for any particular shell. A gear ratio is used to multiply the range by a constant. A clamp offset is used to add another constant to the result to give a rough value of Time of Flight, *Tf,* for any given value of Present Range.

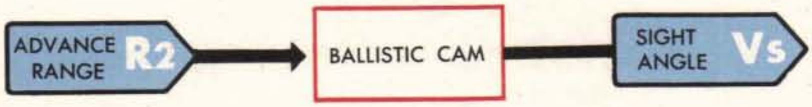
In this network, $Tf = K(cR) + c$

Time of Flight, *Tf,* multiplied by the rate at which range is changing results in Range Prediction, *Rt*. *Tf* becomes an input to a multiplier together with Range Rate, *dR*. The output is Range Prediction, *Rt*.

The Present Range, *cR,* added to Range Prediction, *Rt,* equals the Advance Range, *R2*. *R2* in this network is the range at the end of the time of flight of the shell.



COMPUTING SIGHT ANGLE



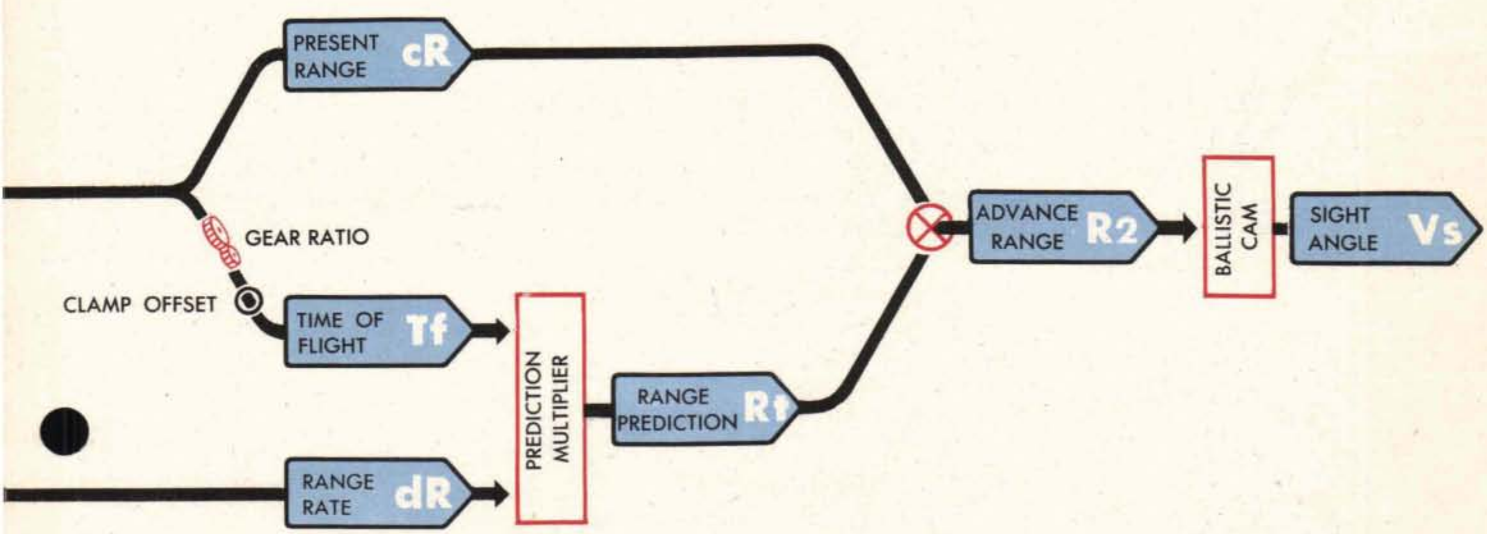
Now Advance Range, *R2,* goes to a flat ballistic cam. This cam is designed so that its output is the Sight Angle, *Vs,* for whatever range is set into it.

The value of *R2* is the input, the output is the value of *Vs* for that value of Advance Range.

THE WHOLE NETWORK

Here's what the whole imaginary network looks like.

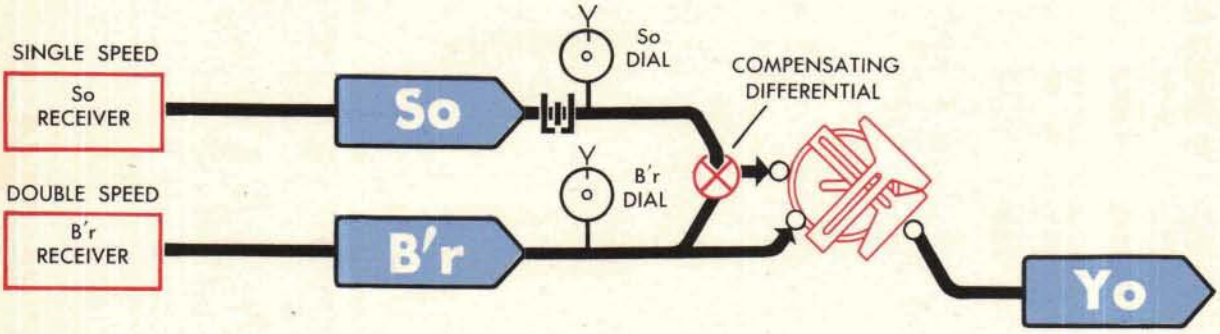
Notice that as the inputs are introduced at the start of the problem, the quantities feed through the mechanism and a corresponding sight angle is immediately computed. Then as the ship and target move with respect to each other, and the inputs to the component solvers change, the network continuously computes a changing value of sight angle.



How the MECHANISMS solve the problem

Here's the same problem of finding sight angle. But in working it out this time, just what happens in each mechanism is shown.

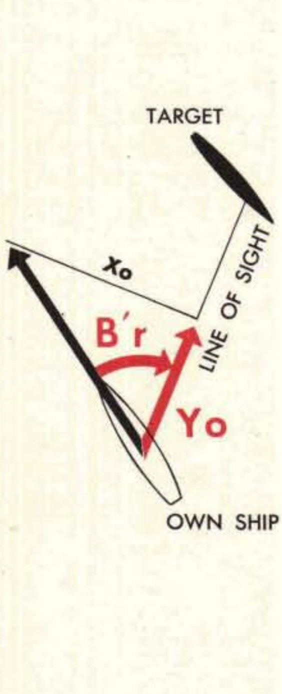
OWN SHIP component solver



Ship Speed, *So*, is assumed to be received electrically from the ship speed transmitter in the pitometer log. The transmitter sends an electrical signal to the *So* receiver and positions its rotor.

The receiver positions the *So* shaft. This shaft positions the *So* dials and the cam of the Ship Component Solver.

There is a limit stop on the *So* line. The limit stop prevents the receiver motor output shaft from jamming the cam follower pin into the end of the cam groove if it overruns the signal.



The fine and coarse motors in the *B'r* receiver accurately position the *B'r* shaft and the vector gear of the component solver. *B'r* also positions the *B'r* dial. In this network *B'r* is not corrected for the effect of deck inclination.

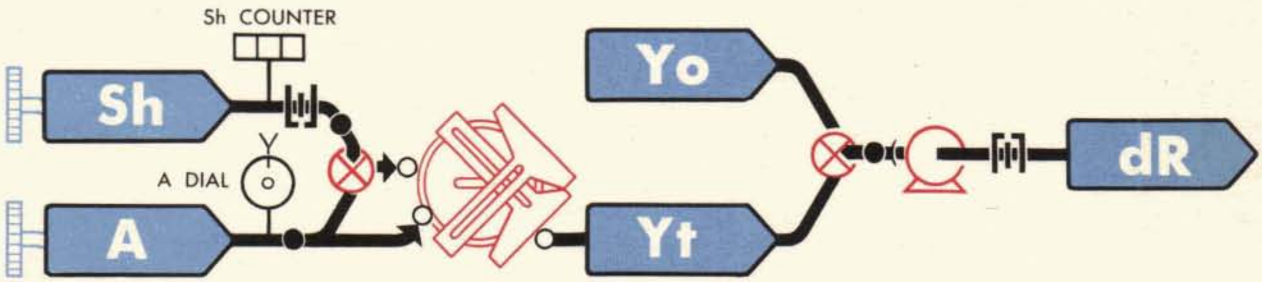
There is a compensating differential on the cam input line of the component solver which prevents any rotation of the vector gear from affecting the radial position of the pin. The compensating differential is explained in the chapter on Component Solvers.

The component solver is positioned by Ship Speed, *So*, and Director Train, *B'r*. The cam and vector gear position the pin and the two output racks. The racks position the output gears.

The only output of interest in this problem is *Yo*, the component of Own Ship Speed *along* the Line of Sight. The other output goes to another network.

$$Yo = -So \cos B'r$$

TARGET component solver



Target Speed, *Sh,* is phoned down from the director. It is set into the Computer by a hand crank. The crank turns a shaft that positions the cam of the Target Component Solver and the Target Speed Counter.

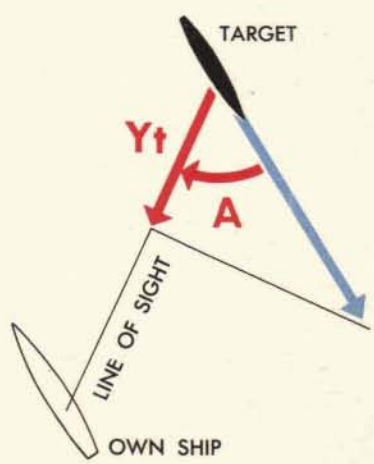
If the *Sh* hand crank should turn past the zero position of the cam, the cam follower would be jammed against the end of the cam groove. A limit stop is put on the *Sh* line to prevent this damage.

Target Angle, *A,* is also phoned down from the Director and is set in by hand crank. The crank turns a shaft that positions the vector gear of the Target Component Solver and the Target Angle Dial.

There is a compensating differential on the cam line.

The output of interest here is *Yt,* the component of target speed *along* the line of sight. The other output goes to another network.

$$Yt = -Sh \cos A$$



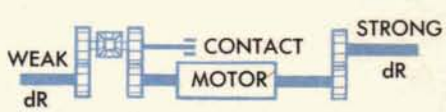
Now the outputs from the component solvers are combined. The sum of the components of ship and target speed, *along* the line of sight is the range rate.

$$dR = Yo + Yt$$

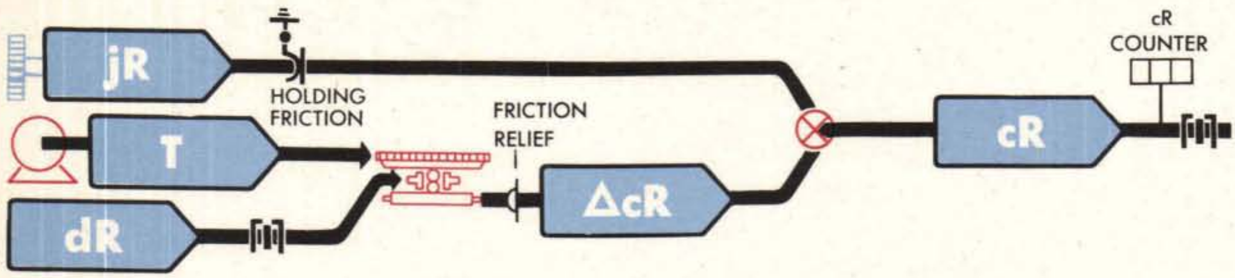
The *Yo* output from the ship component solver positions one side of a differential. The *Yt* output from the target component solver positions the other side. The output on the spider is the sum of the two inputs, Direct Range Rate, *dR,* the rate at which the range between the target and own ship is changing.

The output from the differential is precise, but weak. It has to be made powerful enough to drive the next mechanism in the network. This is done by having the output shaft of the differential drive the input to a servo motor follow-up control.

The *dR* shaft positions one side of the differential in the follow-up. The motor drives the other side of the differential to keep the error shaft on zero and so puts the output line in exactly the same position as the input line. The output from the motor is powerful enough to drive the next mechanism.



The DISK INTEGRATOR



The dR shaft positions the carriage of a disk integrator.

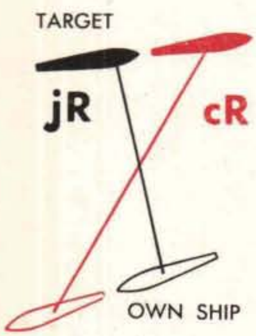
The input to the integrator carriage must be held within the limits of travel of the carriage. Therefore a limit stop is put in the dR line between the follow-up control and the integrator.

The Time Motor, whose speed is kept constant by a motor regulator, turns the disk of the integrator. This input to the disk is Time. The output on the roller represents Generated Changes in Range, ΔcR.

Initial Range Setting, jR, added to Generated Changes in Range, ΔcR, gives Present Range, cR.

$$cR = jR + \Delta cR$$

In this example, initial range is set in the computer by turning the jR handle until the present range counter reads the value of present range which has been phoned down from the director.

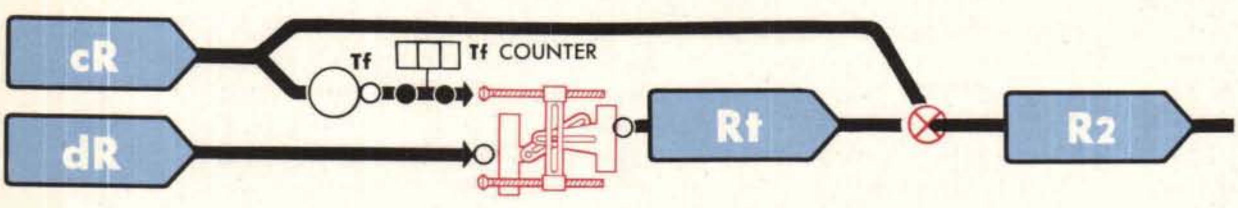


There is a holding friction on the jR line so that as changes of Range are generated, this output of the integrator will drive into the cR line without upsetting the initial setting of the jR line.

There is a limit stop in the cR line to protect the mechanisms driven by that line.

The output line from the integrator has a friction relief. When the value of Present Range reaches its limit, and the integrator output is stopped by the limit stop on the cR line, the friction will slip allowing the integrator roller to turn and so preventing excessive wear in the integrator.

The MULTIPLIER



Time of Flight, Tf, is assumed to be approximately proportional to Present Range. A gear ratio and clamp offset are used to solve this equation:

$$Tf = K(cR) + c$$

A gear ratio multiplies Present Range, cR, by a constant, K. The output of the gear ratio is then $K(cR)$.

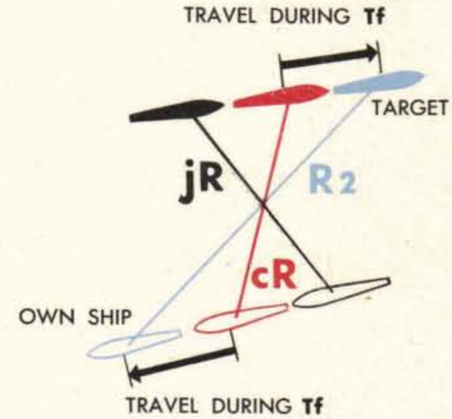
A clamp offset adds another constant, c. This solves the equation and the result is an approximate Time of Flight, *Tf*, which positions the screw of the prediction multiplier.

The Range Rate, *dR*, coming from the follow-up output line moves the input rack of the multiplier.

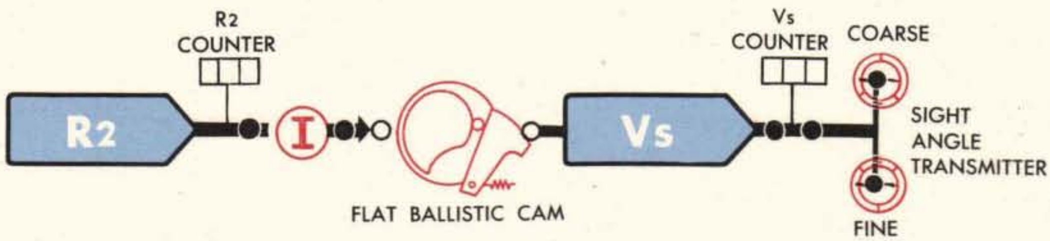
The output from the multiplier is proportional to the Range Prediction, *Rt*. Range Prediction is the change in the range during Time of Flight.

Then the Range Prediction shaft positions one side of a differential. The other side is turned by a branch of the Present Range line. The output on the spider is Advance Range, which is the sum of *cR* and *Rt*.

$$R2 = cR + Rt$$



The BALLISTIC CAM



The *R2* line goes to the ballistic cam. There is an Intermittent Drive in this line because the ballistic cam is designed to handle only range values within certain limits.

The Intermittent Drive cuts out when advance range is below the lower limit or above the upper limit of the cam. As a result the Advance Range shaft on the output side of the Intermittent Drive transmits only ranges within the limits of the cam.

The *R2* shaft puts a reading into the *R2* counter and positions the input gear of the flat ballistic cam. This cam is designed so that for every input of advance range, it gives the correct Sight Angle, *Vs*.

$$Vs = f(R2)$$

As the input gear puts the Advance Range into the cam, the output gear, meshed with the sector arm, is positioned to give the value of Sight Angle for that range.

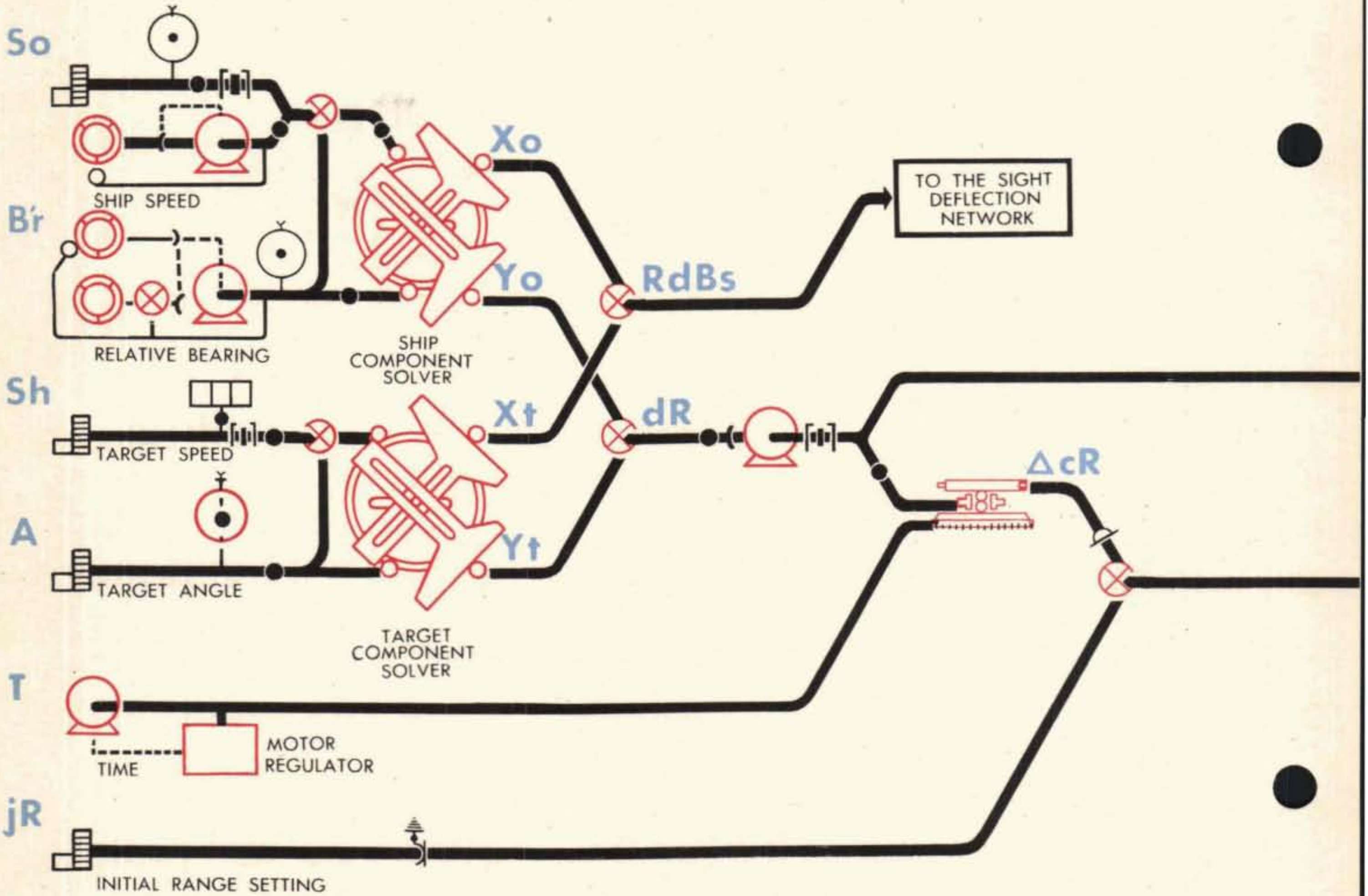
The *Vs* output shaft puts this Sight Angle value into the *Vs* counter and at the same time positions the rotors of the fine and coarse *Vs* transmitter generators. The *Vs* transmitter sends an accurate electrical signal to the synchro receivers in the turrets.

Here's the complete network with the

The inputs to the networks keep changing all the time that the target is being tracked. Each change of the initial inputs to the network immediately changes the values all along the line, including the final output—Sight Angle. In this way the network keeps on computing Sight Angle for the changing conditions.

It should be noted that the output value is *instantaneously* computed. That is, the output always reads the correct value for the inputs in the network at that instant. The time line—through the integrator—keeps present range on the correct value while the value of dR is continually corrected by changes in the component solver inputs during tracking.

The output, Vs, is up to date *at any instant.*



MECHANISMS shown

Although this is a simplified network, the equation it continuously solves illustrates most of the mathematics needed to solve fire control problems by mechanical means.

$Vs = f\ (R2)$ where $R2 = Rt + cR$
$Vs = f\ (Rt + cR)$ where $Rt = dR \times Tf$
$Vs = f\ [(dR \times Tf) + cR]$ where $dR = Yo + Yt$
$Vs = f\ \{[(Yo + Yt) \times Tf] + cR\}$ where $Tf = K \times cR + c$
$Vs = f\ \{[(Yo + Yt) \times (K \times cR + c)] + cR\}$ where $cR = \Delta cR + jR$
$Vs = f\ \{\{(Yo + Yt) \times [K(\Delta cR + jR) + c]\} + \{\Delta cR + jR\}\}$

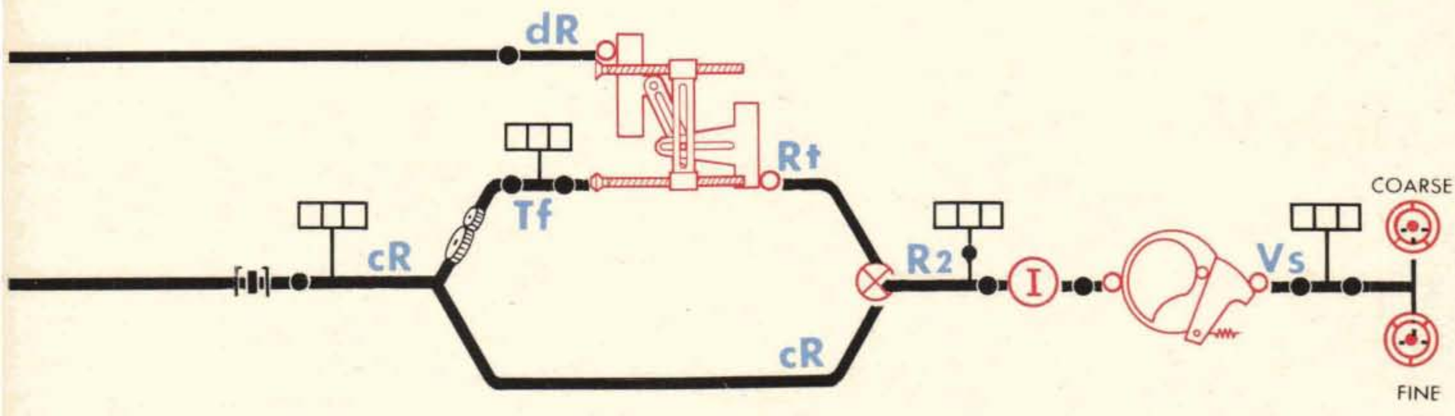
where ΔcR, the accumulated increments or changes of range, is represented this way:

$$\int dR \times \Delta T$$

and $Yo + Yt$ is represented this way:

$$-So \cos B'r - Sh \cos A$$

$$Vs = f\ \{\{[-So \cos B'r - Sh \cos A] \times [K(\int dR \times \Delta T + jR) + c]\} + \{\int dR \times \Delta T + jR\}\}$$

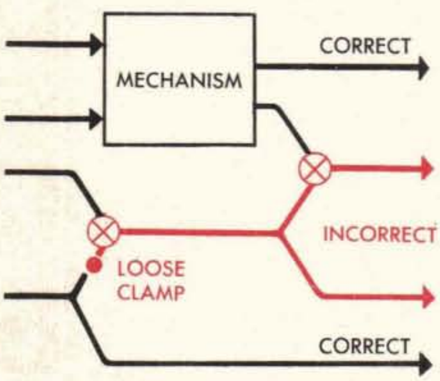


SETTING the NETWORK

A setting method for each basic mechanism considered separately has already been described. Now it is necessary to take into consideration the setting of a *network* of mechanisms. The mechanisms within a network have to be set to each other. Then a network acts as a unit and computes the correct output for the values put in.

In the description of the setting of the basic mechanisms it was assumed that there was a counter on each input and output shaft. In an actual computer this is not so. Counters are placed only where they are needed as reference points.

The order of settings is established to create a "progressive reference point." This means that as each setting is made, its result is used as the basis for the next setting.



THE LINES AFFECTED BY THE LOOSE CLAMP ARE SHOWN IN RED

If any clamp in a network becomes loose, or is improperly set, it upsets the entire network from that point on. All the mechanisms that follow the upset clamp receive incorrect inputs. This acts as a constant offset and introduces an error to all the outputs of the network after the upset clamp. The mechanisms before the upset clamp are not affected.

In setting a network, the input to each mechanism is set to the output of the mechanism before it. In this way, each setting requires that the network up to that point has been correctly set. Putting an error into one clamp to compensate for the error in a previous clamp is to be avoided. The only remedy is to locate the clamp that is upset and correct it.

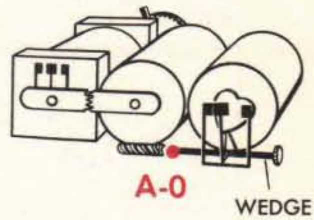
To show the principles of setting a network, these instructions are given for setting the imaginary network that has just been described. The clamp numbers (*A-0, A-1,* etc.) used are for convenience only and do not refer to any specific computer. They were chosen only as examples. ALL adjustment clamps must be loose before starting to set the network.

A-0 COARSE AND FINE SYNCHROS in B'r RECEIVER

Set the fine synchro at electrical zero. Turn the servo output until the fine contacts are centralized, slip-tighten the clamp and wedge the output shaft.

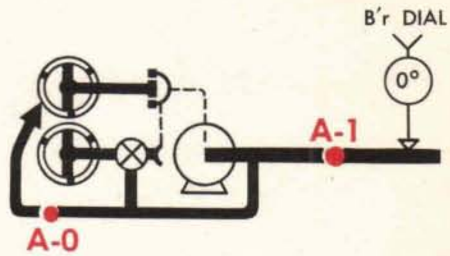
Set the coarse synchro at electrical zero and slip the clamp until the coarse contacts are centralized.

Tighten *A-0* clamp.



A-1 B'r DIAL to B'r RECEIVER

With the receiver output shaft still wedged on 0° set the *B'r* dial to 0°. Tighten *A-1* clamp, and remove the wedge.



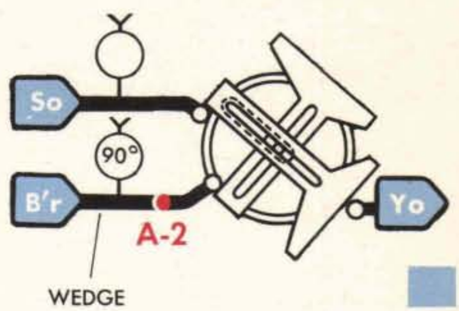
A-2 VECTOR GEAR to B'r DIAL

With *B'r* dial at 90°, wedge the line. Position the vector gear slot parallel to the *Yo* rack slot and pointed away from the *Yo* output. Slip-tighten *A-2* clamp.

Mark the position of the *Yo* output gear on the rack with a pencil line.

Moving the *So* cam should produce *no motion* of the *Yo* rack. This is a rough setting, using a mark on the rack as an indicator. The fine setting is done later on.

Remove the wedge.



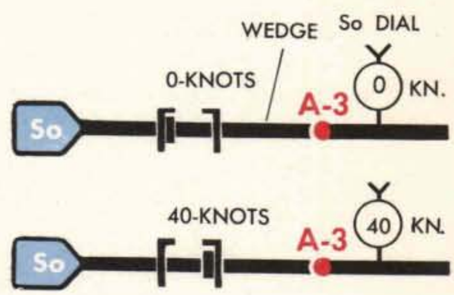
A-3 So DIAL to LIMIT STOP

Slip-tighten *A-3* clamp. Turn the *So* line in a decreasing direction to the end of the limit stop. Wedge the line.

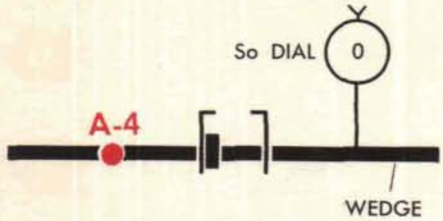
Loosen *A-3*. Put the *So* dial at zero knots. Tighten *A-3* clamp.

Remove the wedge.

Run the *So* line until the limit stop block is at the other end. The *So* dial should read 40 knots.



A-4 So DIAL to So RECEIVER

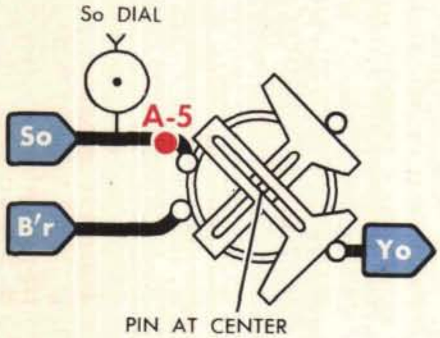


With the *So* dial wedged at zero knots, put the synchro motor at electrical zero.

Synchronize the follow-up by hand with the power OFF. Then energize the servo motor.

Tighten *A-4* clamp.

A-5 So CAM to DIAL



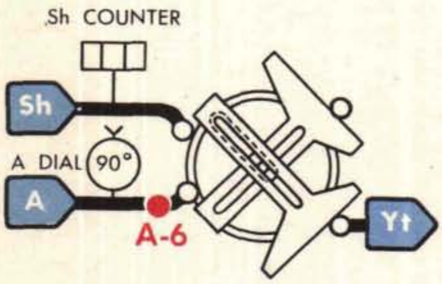
Wedge the *So* dial at zero knots. Position the cam so that the pin is in the center. Slip-tighten *A-5* clamp.

Movement of the *B'r* vector gear should produce no motion of the *Yo* rack. This is a rough setting, using a mark on the rack as an indicator. The fine setting is done later.

Now the ship's component solver has been approximately set.

Remove the wedge.

A-6 VECTOR GEAR to A DIAL

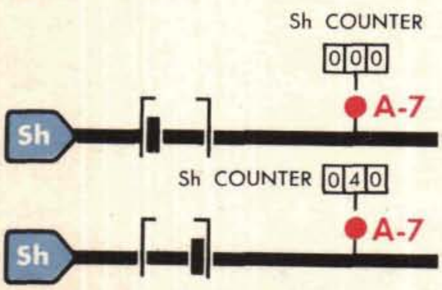


Wedge the *A* dial at 90°. Position the vector slot so that it is parallel to the slot in the *Yt* rack and pointed away from the *Yt* output. Tighten *A-6* clamp.

With the *A* dial at 90°, mark the position of the *Yt* output gear with a pencil line. Run *Sh* line. There should be no output on the *Yt* rack. This is a rough setting, using the rack as an indicator.

This setting is refined later.

A-7 Sh COUNTER to LIMIT STOP



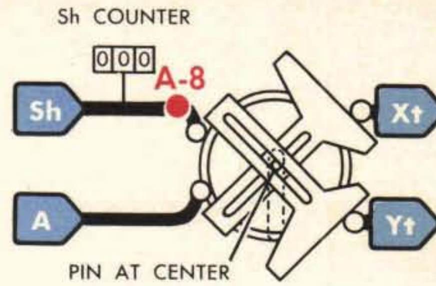
Slip-tighten *A-7*. Run the *Sh* line in a decreasing direction to the end of the limit stop. Wedge the *Sh* line.

Loosen *A-7*. Put the *Sh* counter at zero knots. Tighten *A-7*.

Remove the wedge.

Run *Sh* to the other end of the limit stop. The *Sh* counter should read 40 knots.

A-8 Sh CAM to COUNTER



Wedge the *Sh* counter at zero knots. Position the cam so that the pin is in the center. Slip-tighten *A-8* clamp.

Movement of the *A* vector gear should produce no motion of either output rack. This setting is refined later.

Now both the ship and target component solvers are approximately set.

A-9 dR FOLLOW-UP to the D-I DIFFERENTIAL

Wedge the *Sh* counter and the *So* dial at zero knots. This gives a zero output from the differential because both inputs are zero.

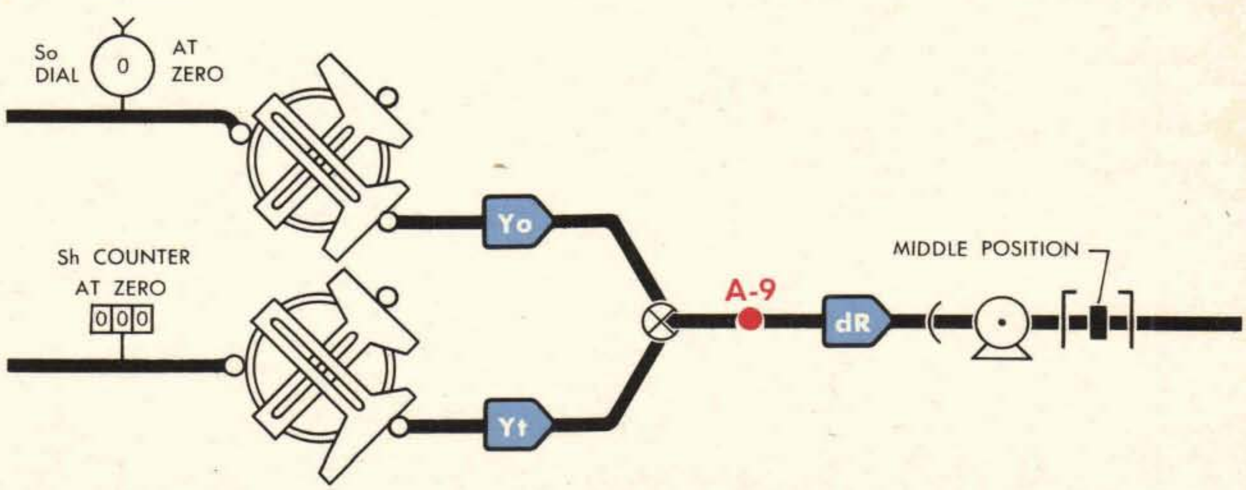
Run the follow-up output to both ends of the limit stop by hand. This is to make sure that mechanisms farther along the line are not upset in such a way that the running of the motor could damage them.

Position the traveling nut of the limit stop on the *dR* line about in the center.

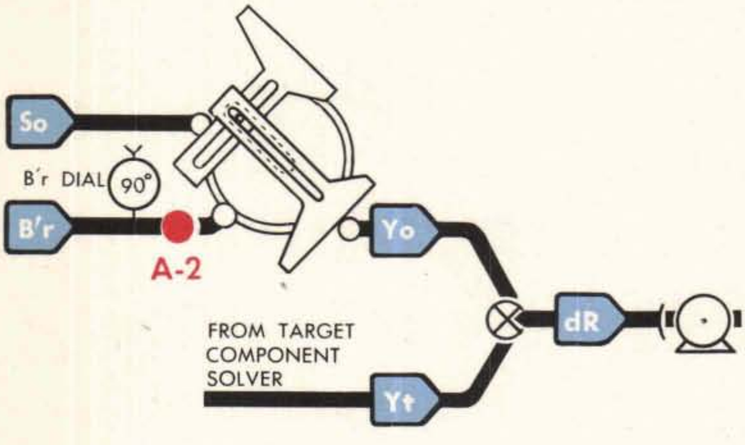
Synchronize the follow-up. When the follow-up is energized, the traveling nut in the limit stop should remain in the middle position. Tighten *A-9* clamp. Remove the wedges.

This is a temporary setting. It will have to be done over again after the setting of the component solvers has been refined.

> Another way to set this section of network would be to set the component solvers with a shadow stick or dial indicator. This would give an accurate setting at once. Then the refined settings would not be necessary, and the *A-9* clamp would require only one setting.
>
> If the solvers are approximately set first and then refined, the follow-up setting has to be done twice. However, this gives a more accurate setting because the follow-up acts to remove any lost motion in the mechanisms.



REFINING the SETTING of the COMPONENT SOLVERS



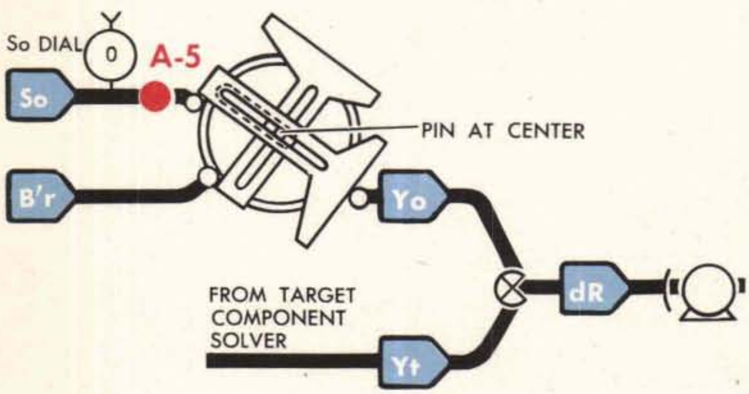
A-2 VECTOR of SHIP SOLVER to B'r DIAL

Set the *B'r* dial at 90°.

Wedge the *Sh* and *A* lines to hold the *Yt* side of the *dR* differential, so that no motion can back out through that side.

Turning the *So* cam with the *dR* follow-up energized should produce no output from the follow-up. If any correction has to be made, it should be done with *So* at 40 knots. Slip-tighten *A-2* clamp. Wedge *B'r* dial and adjust the vector gear until there is no output.

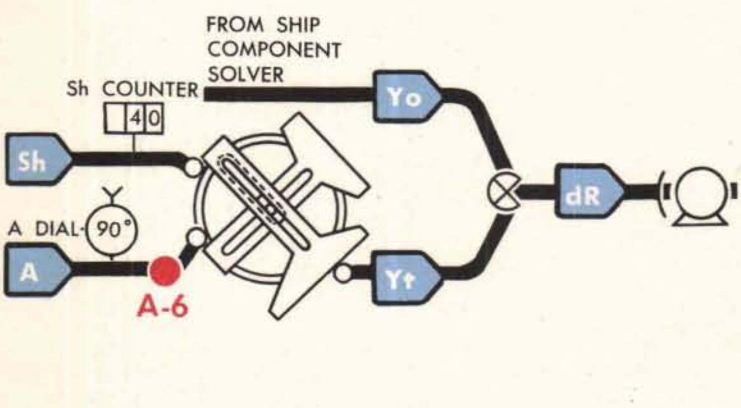
Tighten the *A-2* clamp. Remove the wedge on the *B'r* line.



A-5 CAM of SHIP SOLVER to So DIAL

Put the *So* dial at zero knots. Wedge the *Sh* and *A* lines to hold the *Yt* side of the *dR* differential so that no motion can back out that side. Turning the *B'r* vector should produce no output from the *dR* follow-up. Wedge *So* dial at 0 knots. Slip through *A-5* clamp to adjust the cam position.

Tighten the *A-5* clamp. Remove all wedges.



A-6 VECTOR of the TARGET SOLVER to A DIAL

Set the *A* dial at 90°. Wedge the *So* and *B'r* lines to hold the *Yo* side of the *dR* differential so that no motion can back out of that side.

Turning the *Sh* line should produce no output from the *dR* follow-up. Any correction that is required should be made with *Sh* at 40 knots. Wedge the *A* dial at 90°. Slip through clamp *A-6* to position the vector gear.

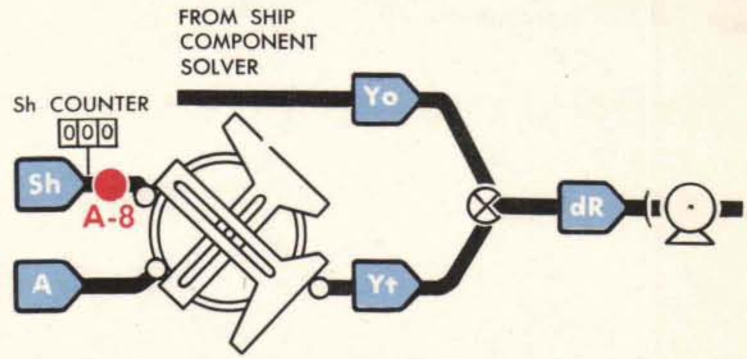
Tighten the *A-6* clamp. Remove the wedge on the *A* line.

A-8 CAM of TARGET SOLVER to Sh COUNTER

Run the *Sh* counter to zero knots. Wedge the *So* and *B′r* lines to hold the *Yo* side of the *dR* differential so that no motion can back out of that side.

Turning the *A* vector should produce no output from the *dR* follow-up. Wedge the *Sh* counter. Slip through *A-8* clamp to position the cam.

Tighten the clamp. Remove all wedges. Now that the settings for the component solvers have been refined, adjustment *A-9* of the *dR* follow-up has to be repeated. The previous setting was only a temporary one. This time it is a final setting.



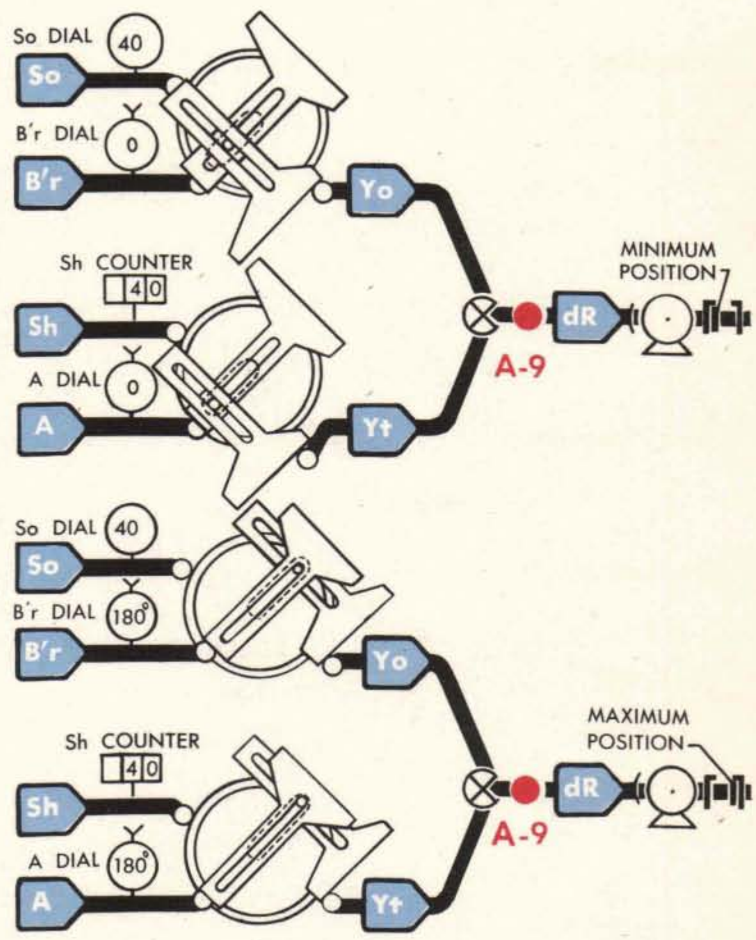
A-9 FINAL SETTING of the dR FOLLOW-UP

With *A* and *B′r* at 0°, put *So* and *Sh* at 40 knots. Synchronize the *dR* follow-up so that the *dR* limit stop traveling nut just touches the minimum end of the stop.

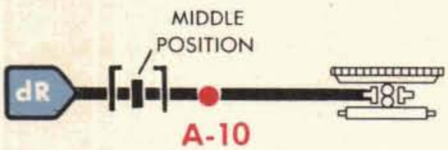
Run *A* and *B′r* to 180°. The follower block should just touch the maximum end of the stop. If there is any error, it should be split at both ends of the stop.

Then tighten the *A-9* clamp.

In general, if one limit of a limit stop is at a zero value, the stop is set exactly to this value to give a definite reference point. When the limits are above and below zero, as in the case of *dR*, the error should be "split" so that there is equal error at both ends.



A-10 CARRIAGE OF DISK INTEGRATOR TO dR FOLLOW-UP

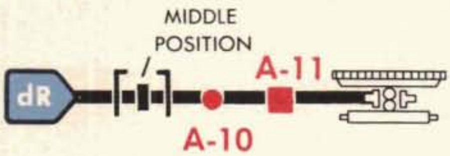


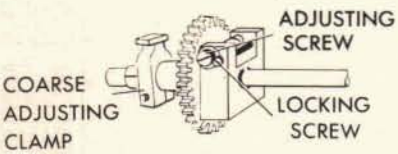
Put *So* and *Sh* at zero knots with the follow-up energized. This makes $dR = 0$.

Position the integrator carriage approximately in the center of the disk. The traveling nut in the limit stop will be at its middle position.

Tighten *A-10* coarse clamp. This is a rough setting.

A-11 VERNIER TO REFINE INTEGRATOR CARRIAGE SETTING





To refine the setting of the carriage, turn the adjusting screw of the *A-11* vernier clamp to put the carriage in the exact center of the disk.

Check the setting by running the disk. Adjust through the adjusting screw of the vernier until there is no output from the integrator roller.

Then carefully tighten the locking screw of the vernier. Now check the setting to make sure that tightening the locking screw has not upset the adjustment of the vernier.

A-12 INPUT RACK OF THE PREDICTION MULTIPLIER

With *dR* at zero, position the input rack until its slot is parallel to the slot in the output rack.

Position the input slide so that the multiplier pin is approximately over the stationary pin. Slip-tighten the *A-12* clamp.

Position a shadow stick between the output gear teeth. Run the slide to the farther end of the screw. There should be no movement of the shadow.

If motion is observed, hold the line, *dR*, and push the input rack until the shadow stick returns to its original position.

Repeat the test until there is no movement shown by the shadow stick.

Always correct the setting with the slide at its maximum distance from the fixed pin.

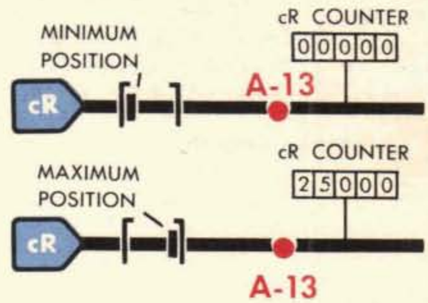
Tighten *A-12* clamp and remove the shadow stick.

A-13 cR LIMIT STOP

Run *cR* in a decreasing direction to the end of the limit stop and wedge the line.

Put *cR* counter at zero yards. Tighten *A-13* clamp and remove the wedge.

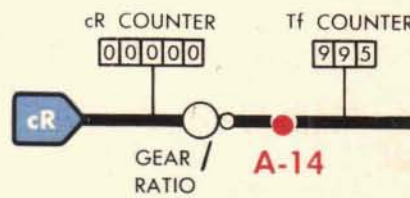
Run the *cR* counter to 25,000 yards. The block in the limit stop should be at maximum position.



A-14 Tf COUNTER TO cR COUNTER

With *cR* counter at zero yards, wedge the line. Set *Tf* counter at minus five seconds. Zero for this counter is 000. Minus five would appear as 995.

In this network the value of *Tf* is only an approximation. A five second offset is put on the line so that errors in *Tf* will be as small as possible.



A-15 MULTIPLIER PIN TO Tf COUNTER

With the *Tf* counter at zero seconds, wedge the line. Set the multiplier screw input at zero, over the stationary pin. Then the multiplier pin is in the middle of the rack travel since *dR* going to the rack can be plus or minus.

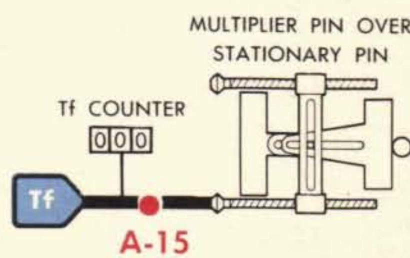
Since the stationary pin is in the center, only half the error has to be corrected when this error is read as movement of the output rack during the full travel of the input rack.

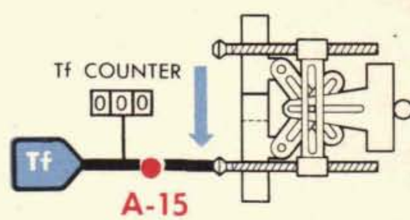
Position a dial indicator on one end of the output rack if it is easy to reach. Otherwise, use a shadow stick to measure the output rack movement.

Move the input rack all the way from one side to the other. Then run the input rack all the way in the other direction. There should be no motion on the indicator. If there is, the multiplier pin is not directly over the stationary pin.

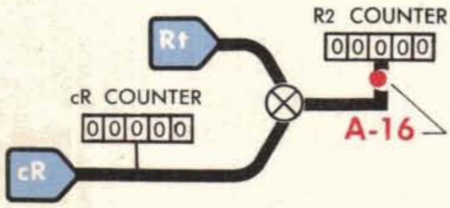
Then with the input rack at one end, re-position the multiplier pin. Run the input rack all the way in the other direction again. When there is no motion shown on the indicator, tighten *A-15* clamp.

Rt is now set to *Tf*.





A-16 R2 COUNTER TO cR COUNTER



Set the *So* dial and *Sh* counter at zero. This makes *dR* zero. When *dR* is zero, *Rt* will be zero.

Set the *cR* counter at zero. Then because *Rt* is zero and *cR* is also zero, *R2* is zero since $R2 = cR$ plus Rt.

Set the *R2* counter at zero and tighten *A-16* clamp.

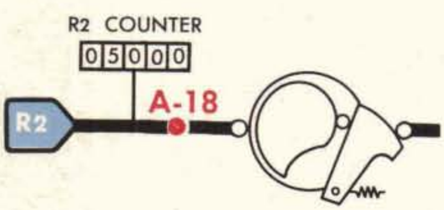
A-17 INTERMITTENT DRIVE to R2 COUNTER

Set the *R2* counter at zero. This is the cut-in reading for the lower limit of the intermittent drive. Run the intermittent drive until it cuts in at the lower limit. Slip-tighten *A-17* clamp.

Run the *R2* counter to 25,000 yards. This is the cut-out reading for the upper limit of the intermittent drive. Slip the line to the intermittent drive to increase the input slightly and check that the unit cuts out immediately. Tighten the clamp and check the lower limit.

When checking the setting of the intermittent drive, put *So* at 40 knots and have *B'r* at 0° for checking the lower limit and *B'r* at 180° for checking the upper limit. Then for either limit, *R2* will reach its cut-out value BEFORE *cR* reaches its limit and turning the *cR* line will carry the *R2* line past its cut-out value. Then if the intermittent drive is set to cut out at some point beyond the limit, this fact can be observed.

A-18 BALLISTIC CAM TO R2 COUNTER



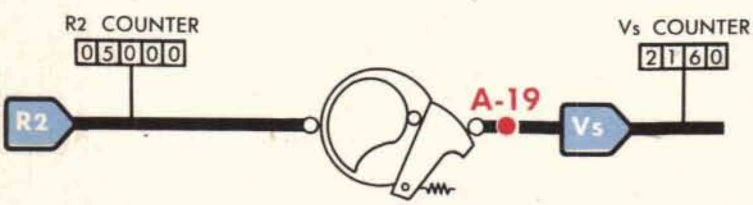
Set *R2* counter at 5000 yards. Insert the ballistic cam setting rod in the cam.

Tighten the *A-18* clamp. Leave the setting rod in the cam.

A-19 Vs COUNTER TO R2 COUNTER

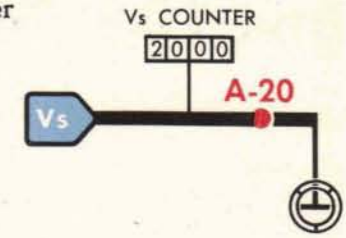
With the *R2* counter at 5000 yards and the setting rod still in the cam, set *Vs* counter at 2160 minutes.

Tighten *A-19* clamp and remove the setting rod from the cam.



A-20 FINE TRANSMITTER TO Vs COUNTER

With the *Vs* counter at 2000 minutes, set the fine transmitter at electrical zero and tighten *A-20* clamp.

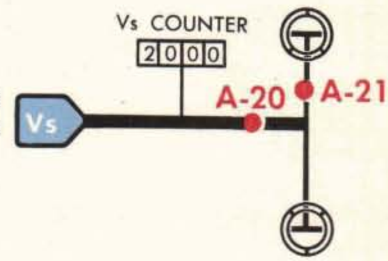


A-21 FINE TO COARSE TRANSMITTER

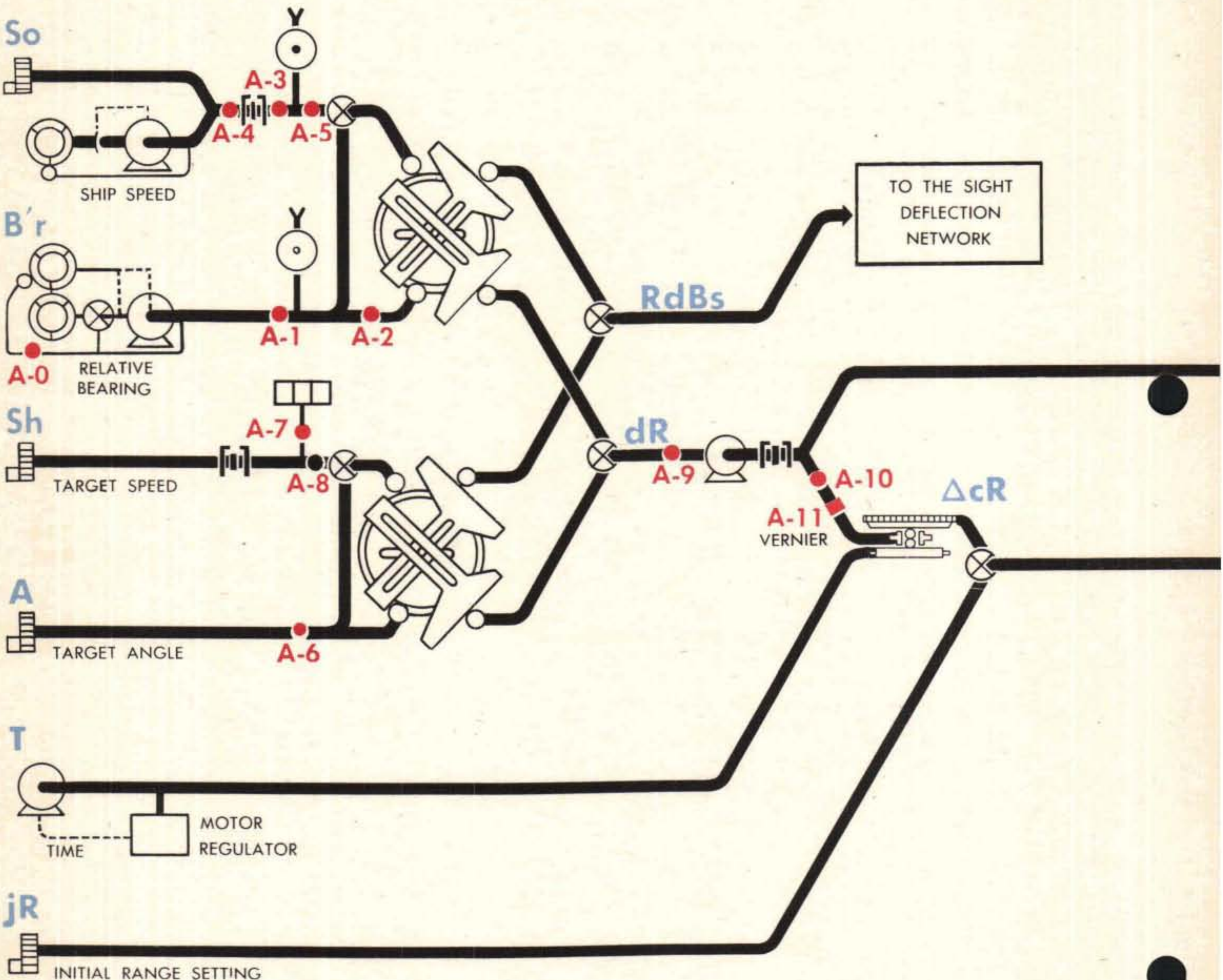
With fine transmitter at electrical zero and *Vs* at 2000 set coarse transmitter to electrical zero.

Tighten the *A-21* fine-to-coarse clamp.

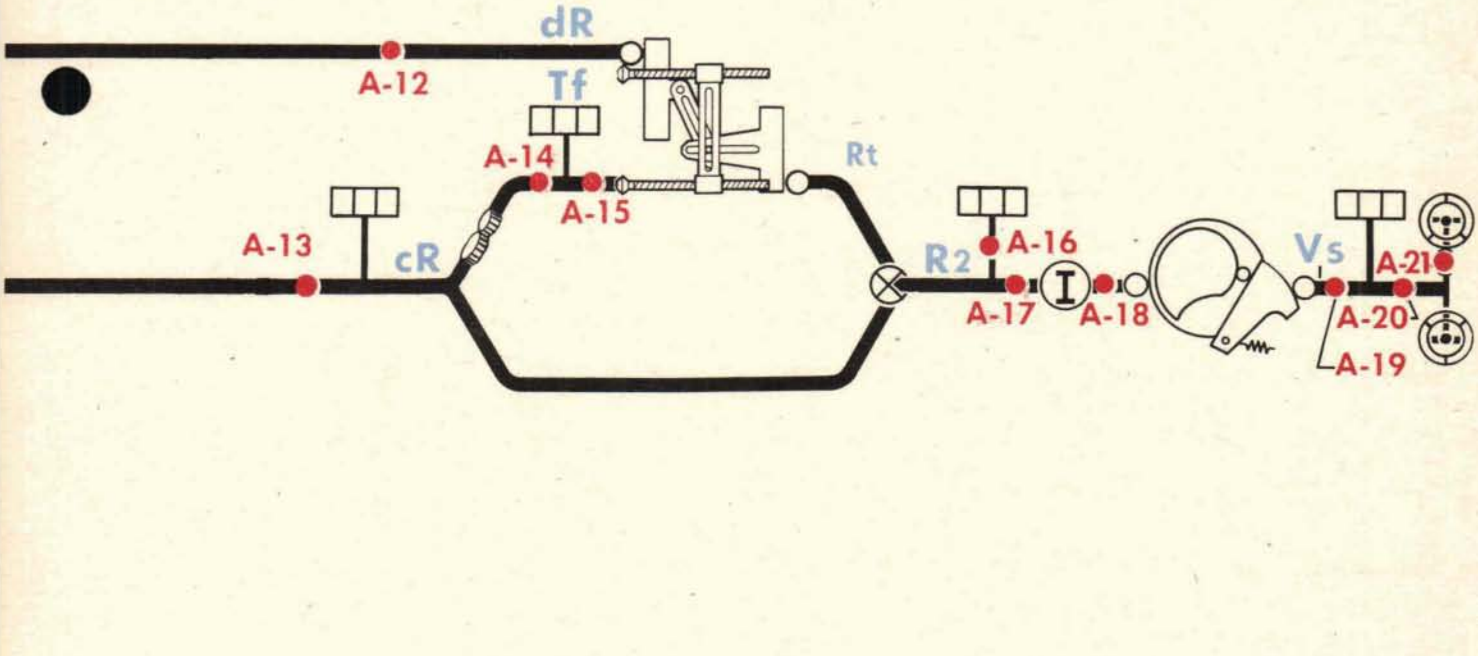
Now the entire network has been set. For any given set of input values, the computed value of Sight Angle will appear on the *Vs* counter and be transmitted to the guns.



Here's the network showing all



the SETTING CLAMPS

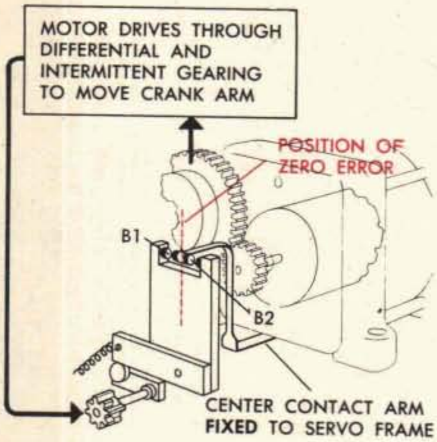


SECTION 5

TECHNICAL APPENDIX

This technical appendix contains descriptive material which was thought to be either too lengthy or too technical to be included in the regular chapters. Most of the appendix is devoted to three devices that are often used in follow-up controls: the Magnetic Drag, the Magnetic Damper, and the Compensator. An explanation of how the Servo Motor works and what the Capacitor does is also included.

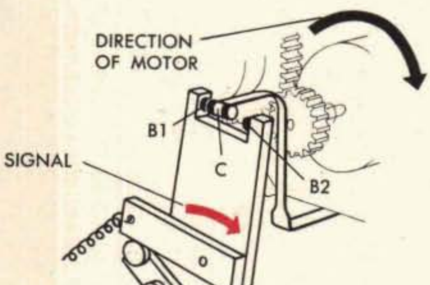
MAGNETIC DRAG



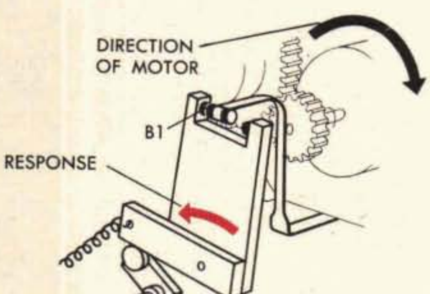
It has been noted that the center contact arm of a follow-up control may be mounted on a shaft rotated, within certain limits, by the core of a magnetic drag, and that such an arrangement is used to bring the servo motor quickly to rest at the point of synchronism.

To understand why such a device is needed, suppose for a moment that a follow-up has no damper or magnetic drag and that the center contact arm is fixed to the frame of the servo in a vertical position, that is in the position of zero error.

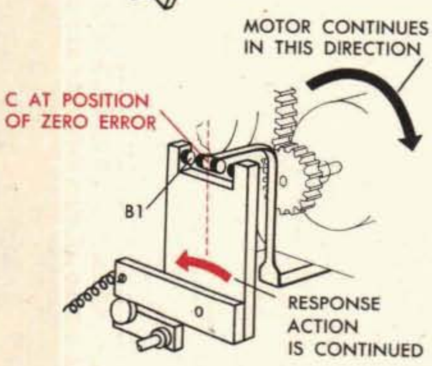
Action of servo without magnetic drag



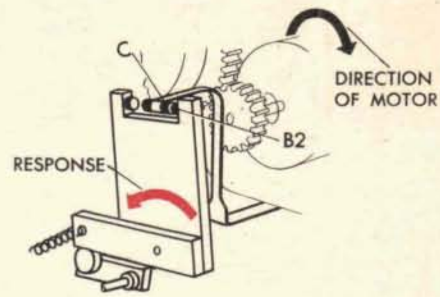
An input from a signal will cause the outer contact arm to rotate and bring an outer contact against the center contact– say outer contact *B1* against center contact C, as shown here.



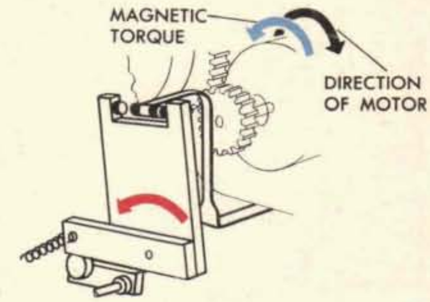
The servo will start, and quickly pick up speed. The response, acting through the differential, will drive *B1* back until the point of zero error is reached.



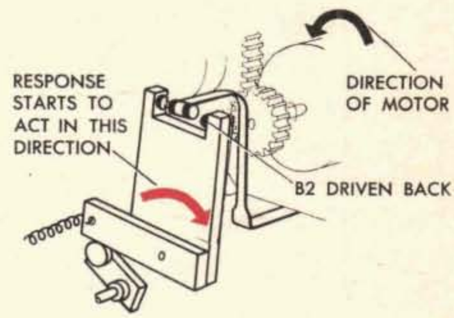
At this point *B1* will be separated from C. However, the servo motor continues to drive in its original direction because of the inertia *of the rotor and shafting even after the current supply is cut off*. This continued rotation of the rotor results in response action being continued.



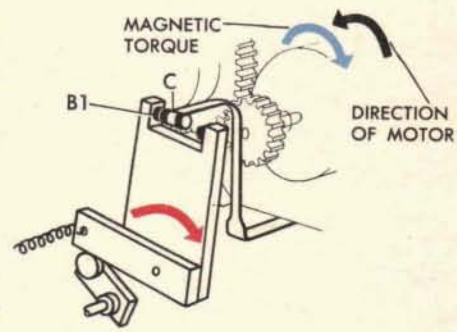
The response continues to rotate the outer contact arm and the other outer contact, *B2,* is brought against the center contact *C.*



Action of the magnetic field in the motor is now reversed, producing a torque acting on the rotor in the opposite direction. This torque slows down the rotor and then reverses it.



When the rotor reverses, contact *B2* is driven back as the response turns the outer contact arm in the opposite direction.



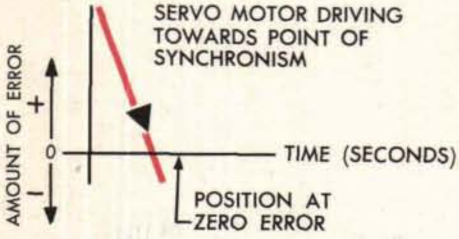
Once more the motor picks up speed and, again because of the inertia in the rotor and connected shafting, overruns the point of synchronism after the circuit is broken. Contacts *B1* and *C* are again brought together, the magnetic torque is applied to the rotor, and the cycle is repeated.

This tendency of the rotor and connected shafting to rotate after the current supply is cut off results in a series of oscillations. In this simplified setup, with the center contact arm fixed to the servo frame, such oscillations would cause the motor to reverse direction and overrun the signal each time an outer contact is swung against a center contact.

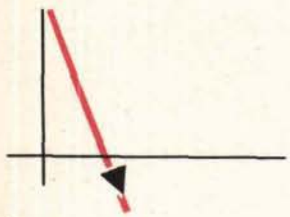
Such oscillations may be repeated many times, although they will finally be reduced to zero as friction and the load on the output shafting bring the rotor to a standstill.

It is the purpose of the magnetic drag to reduce quickly the extent and number of these oscillations.

Servo rotor drives past the point of synchronism many times

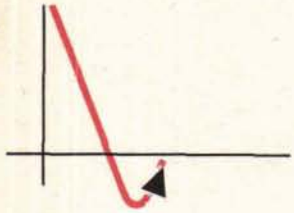


The action of the servo motor, in synchronizing to a fixed signal, can be followed in detail if it is represented in a short series of graphs. By using the vertical axis of the graph to represent the amount the rotor turns after reaching the point of synchronism (i.e., the displacement of the rotor from the value of the signal) and the horizontal axis to represent *time*, a picture is obtained of the rotor's displacement from zero position at any given moment.

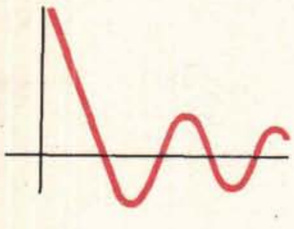


As the current is cut off at the point of zero error (which lies in the horizontal axis of the graph) the servo continues to run at high speed, due to the momentum of its rotor.

The servo thus crosses the horizontal axis at high speed.



As the opposite contact is closed, the current is reversed and this tends to drive the motor in the opposite direction, back to the zero position. The rotor slows, stops, and starts back towards zero. Without drag or damper, it crosses the zero line again with almost the same speed as it had the first time.



In this way, the servo will continue to cross and re-cross the horizontal axis for a long time, due to the oscillations between the contacts of the follow-up control, until friction and the load on the powered shafting finally compel the rotor to come to rest.

Reduction of oscillations

When a magnetic drag is geared to the servo, the tendency of the motor to overrun the point of synchronism is counteracted in such a manner that the oscillations are greatly reduced, resulting in the motor being brought quickly to rest at the point of zero error.

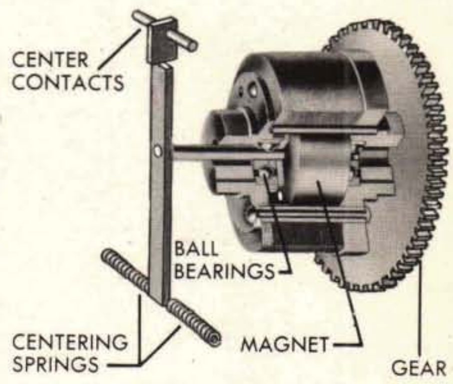
In order to understand how the drag works, it is necessary first to examine its construction and principle of operation.

Construction of the magnetic drag

The magnetic drag consists of two major parts: a frame, and a magnetized core.

The frame is a cylindrical case of laminated construction, made up of thin steel rings held together with copper bars. At each end is a copper end ring into which the bars are fitted. The frame, therefore, is of "squirrel cage" design. It is mounted in bearings at each end and carries a gear which is driven by a servo motor.

The core consists of a solid, magnetized steel cylinder. This core forms a permanent magnet, and is hereafter referred to as "the magnet." This magnet is fixed to a shaft which extends through the center of the case, and to this shaft is fixed the arm carrying the center contacts. Two centering springs are attached to the bottom of this arm.



Principle of operation

The core of the drag, being a permanent magnet, is surrounded by a magnetic field. When the frame is rotated by the servo motor, it carries the copper bars through the field produced by the magnet. A current is induced in the bars, and this current creates its own magnetic field.

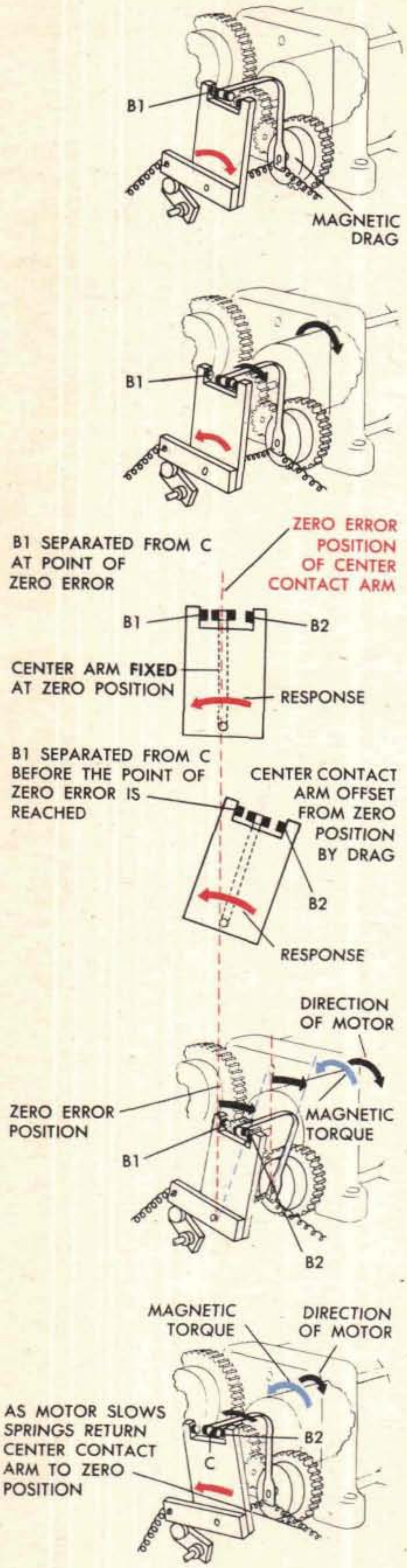
The stator, attached to the frame, tends to pull the magnet around in the direction in which the frame is rotating.

The center contact arm, fixed to the magnet shaft, rotates when the magnet rotates. Two centering springs, however, tend to hold the center contact arm in its zero position, and prevent it from rotating.

When the frame rotates, it must pull the magnet and the center contact arm around against the action of these springs. Because of this, the magnet is able to rotate only a certain distance, offsetting the contact arm from its centered position by a corresponding distance.

The construction of the drag is such that the torque exerted by the rotating frame is almost proportional to the speed of the frame, and the displacement of the centering springs is proportional to the force applied to them, resulting in the center arm being rotated an amount proportional to the speed of the frame. The speed of the frame depends upon the speed of the servo motor. Thus *the center contact arm is pulled around (or displaced from center) an amount proportional to the speed of the motor.*

The drag in action



When the drag is used in a follow-up, this is what happens:

The input from a signal causes an outer contact *B1* to be brought against the center contact C, energizing the motor.

As the motor drives, two things happen: First, the magnetic drag tends to rotate the center contact arm away from *B1*. Then the motor response drives the contact *B1* back (as shown) resulting in the circuit's being broken before the point of synchronism is reached.

If the center contact arm had *remained fixed,* it is obvious that, as the response drove *B1* back, the contacts would have broken at the blue line—the point of zero error.

But when the center contact arm is turned by the drag, the contacts break at the red line, which means that they break *before* the motor reaches the point of zero error—or synchronism. The action of the drag, therefore, can be said to "anticipate" the point of synchronism, causing the contacts to be separated, before the point of zero error is reached.

As *B1* is driven back by the response, *B2* is rotated against a center contact. This means that the action of the magnetic fields in the motor is reversed *before* the point of synchronism is reached.

The motor continues to run in the original direction, because of the inertia of its rotor and connected shafting, and continues to rotate the drag frame in the same direction.

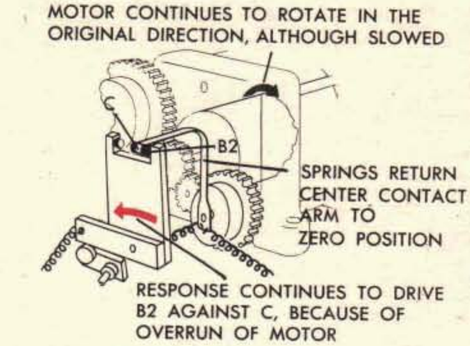
But due to the reversed action of the magnetic fields, a torque is applied to the rotor which tends to pull the rotor around in the opposite direction.

This magnetic torque acts as a brake on the rotor, slowing it down. Thus the speed of the servo motor is decreased before *the point of synchronism is reached.*

As the speed of the servo decreases, the speed of the drag frame, which is geared to the servo, also decreases. Consequently, the strength of the torque coupling between the drag frame and the drag magnet decreases. As this happens, the centering springs act to return the center contact arm to its center position, the position of zero error.

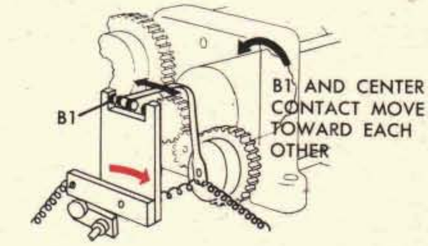
Since the speed of the response decreases as the motor speed decreases, the centering springs move the center contact arm to zero position faster than *B2* is moved by the response, causing the contact between C and *B2* to be broken *before* the point of zero error is reached.

The inertia of the rotor enables it to continue rotating although the action of the magnetic torque has slowed it down. Because of this, response action is sufficient to bring *B2* against the center contact.

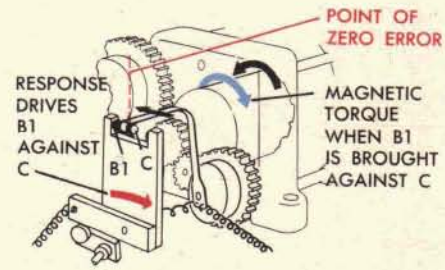


This causes the motor to be energized and to run in the opposite direction.

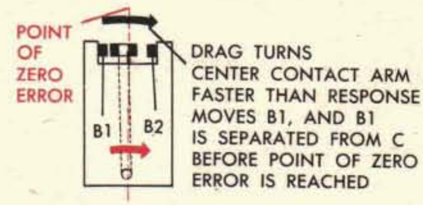
As the motor picks up speed, the drag turns the center contact toward *B1*, and the response turns *B1* toward the center. *B1* and the center contact, therefore, move toward each other.



As the center contact and *B1* touch, on the opposite side of the position of zero error, magnetic torque is applied to the rotor of the motor. The motor speed and drag speed are immediately decreased, and the center contact arm is returned by the springs to the zero position *faster* than the response can move *B1* toward center.



Contact between *B1* and the center contact is therefore broken *before* the point of zero error is reached.

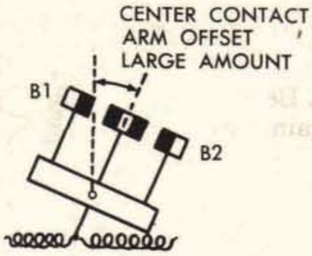


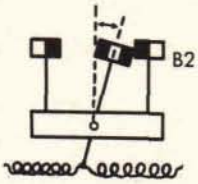
As the rotor of the servo continues rotating, even though the magnetic torque has slowed it down, the drag is turned toward *B2*. At the same time, response action is sufficient to turn *B2* toward center. The cycle described above is therefore repeated. By rotating the center contact arm away from the position of zero error, the magnetic drag causes:

1. the current supply to the motor to be cut off, slowing the rotor, *before* the point of zero error (synchronism) is reached;
2. magnetic torque to be applied, slowing the rotor, *before* the point of zero error (synchronism) is reached.

The action of the magnetic drag can therefore be considered as "anticipating" the point of synchronism by slowing the motor prematurely.

Since the speed of the motor is diminished considerably at each cycle, the amount the center contact arm is rotated at each cycle is considerably diminished also. In other words, the size of the oscillations diminish rapidly, and the motor is brought quickly to rest at point of synchronism.





The gear ratio between the servo and the frame of the magnetic drag (which regulates the speed at which the frame is driven) and the strength of the centering springs can be so regulated that the servo can be stopped practically without oscillations. For instance, if the gear ratio results in the drag frame being rotated at very high speed, and the springs used are weak, the center contact arm can be displaced a considerable amount when the servo runs.

This will result in outer contact *B1* being separated from the center contact while the center contact arm is still at an appreciable distance from its position of zero error.

As the motor overruns the point of synchronism, therefore, *B2* is brought against a center contact, and the current is reversed in the motor coils, while the center contact arm is still some distance from its position of zero error.

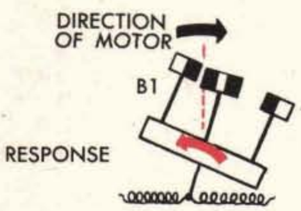
By the time the center contact arm is centered by the springs, the torque has acted sufficiently long on the rotor to bring the rotor to a standstill.

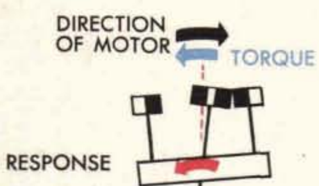
At first glance, this arrangement would appear ideal, as the motor is brought to rest without oscillation.

There is a factor, however, which makes this arrangement undesirable.

When the center contact arm is offset a considerable amount from its center position by the drag, the value of the output lags considerably behind that of the input while following a *moving* signal. The contacts open long before the point of zero error is reached and the response lags behind the signal as long as the signal moves. How this condition is avoided in some follow-up controls is explained later under "The Compensator."

Reducing velocity lag error





To reduce lag error, a compromise is made. The speed at which the drag frame is driven and the strength of the centering springs are so chosen that the center contact arm will not be displaced very far from its center zero position for a given speed.

Under such conditions, the contacts are separated when only a comparatively short distance from the point of zero error—as indicated here, where *B1* is just being driven back from a center contact.

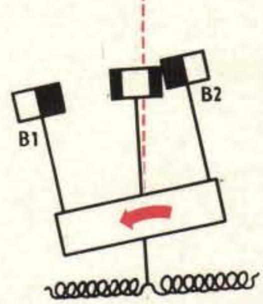
As *B2* is swung over and meets the opposite center contact, current in the motor coils is reversed and a torque is applied to the rotor.

The rotor's speed rapidly decreases, and the centering springs act to bring the center contact back to the zero position.

However, in this case, the center contact arm has been returned to its zero position *before the torque has had time to bring the rotor to rest.*

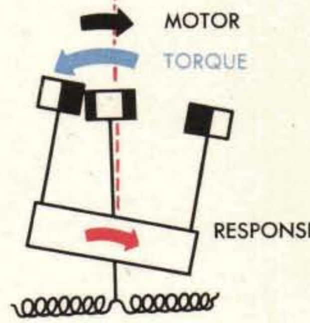
Consequently the motor is still driving in the original direction, although at greatly reduced speed, and this keeps contact *B2* against the center contact.

Under continued application of the torque, the rotor slows down completely and then reverses its direction of rotation.



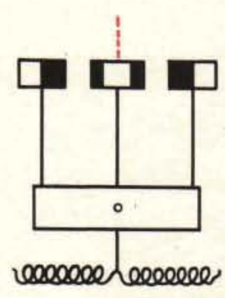
Accordingly, the center contact arm is offset in the opposite direction. Because of the decreased speed of the motor, however, the distance the contact arm is now displaced is *less* than the distance it was displaced initially.

Before the motor has time to pick up any appreciable speed, the servo response, acting through the differential, separates the contacts.



B2 is driven back and the outer contact *B1* is swung over once more. Current is again reversed in the motor coils, and the resulting torque which is applied to the rotor again acts like a brake and slows the rotor down.

Each time the motor crosses the point of synchronism it does so at greatly decreased speed. As the speed of the motor rapidly decreases, the amount the motor overruns the point of synchronism also rapidly decreases.



SPRINGS HOLD ARM CENTERED

With the decrease in speed of the motor, the displacement of the center contact arm becomes less and less. As the motor comes to rest, the centering springs hold the center contact arm at the position of zero error.

When the center contact arm is allowed to move only a comparatively short distance away from the position of zero error, some oscillations will occur between the contacts of the follow-up control, when synchronizing to a fixed signal.

However, since these oscillations rapidly decrease in size (amplitude) and duration, bringing the motor quickly to rest, there is no interference with the efficient working of the mechanism, and lag error in following a changing signal is reduced.

VELOCITY LAG ERROR

In the case of a fixed signal, the action of a magnetic drag introduces no error between the input and the output, for the powered shafting is merely positioned in accordance with the fixed value of the input.

If the powered shafting drifts off its correct position, because of the load, the rotor of the servo will be turned. This will result in the servo response acting through the differential and closing the contacts so that the motor drives the powered shafting back to its correct position.

Output and input are thus kept synchronized at all times during the transmission of a fixed signal.

However, if the signal keeps changing, the action of the drag introduces a difference, or error, between the input and the output while the signal is moving.

This happens because the center contact arm is offset away from the point of zero error by the drag.

If readings are taken at any given instant during transmission of the signal, the reading on the receiver dial will not correspond with the reading on the transmitter dial. The reading on the receiver dial will always be found to "lag" behind that on the transmitter dial.

In other words, the output lags behind the input.

The more the center contact arm is offset from the point of zero error, the greater will be this error, or lag of the output behind the input.

Now, the amount the center contact arm is offset is proportional to the torque exerted by the magnetic drag. This torque depends upon the velocity of the motor.

The velocity of the motor is proportional to the velocity of the incoming signal.

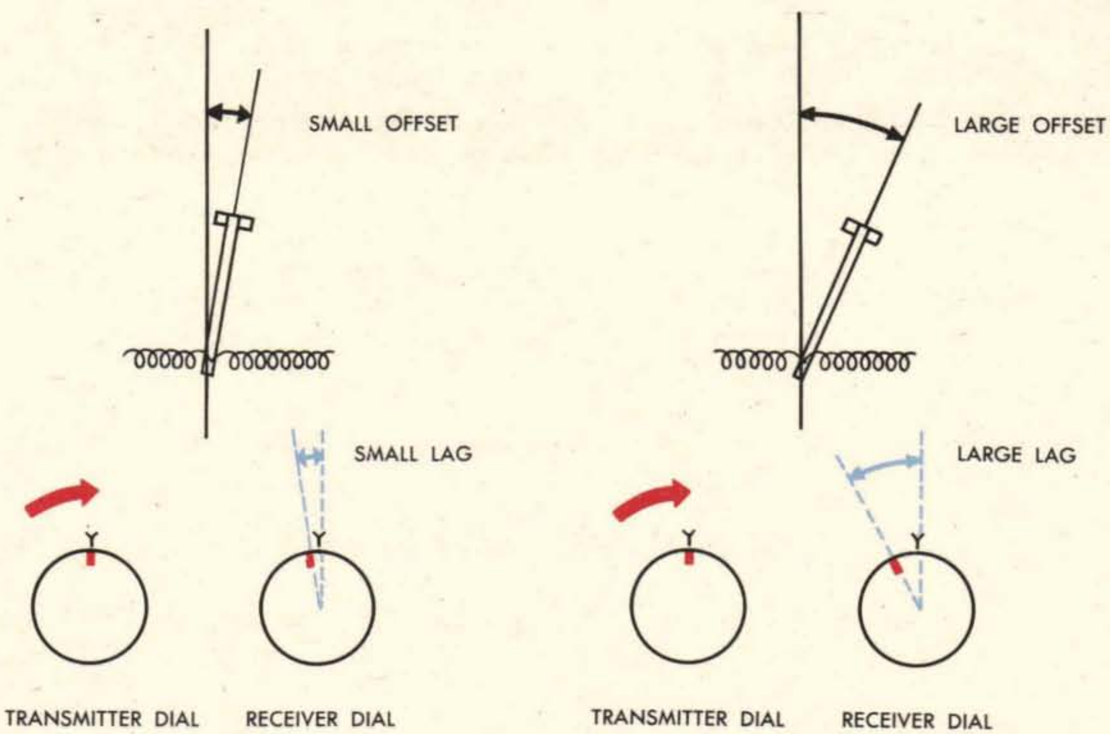
Therefore the error between the input and the output, while the signal is changing, is proportional to the velocity of the signal.

This error is known as the "velocity lag error." Follow-ups having no provision for correcting velocity lag error are called velocity lag type follow-ups.

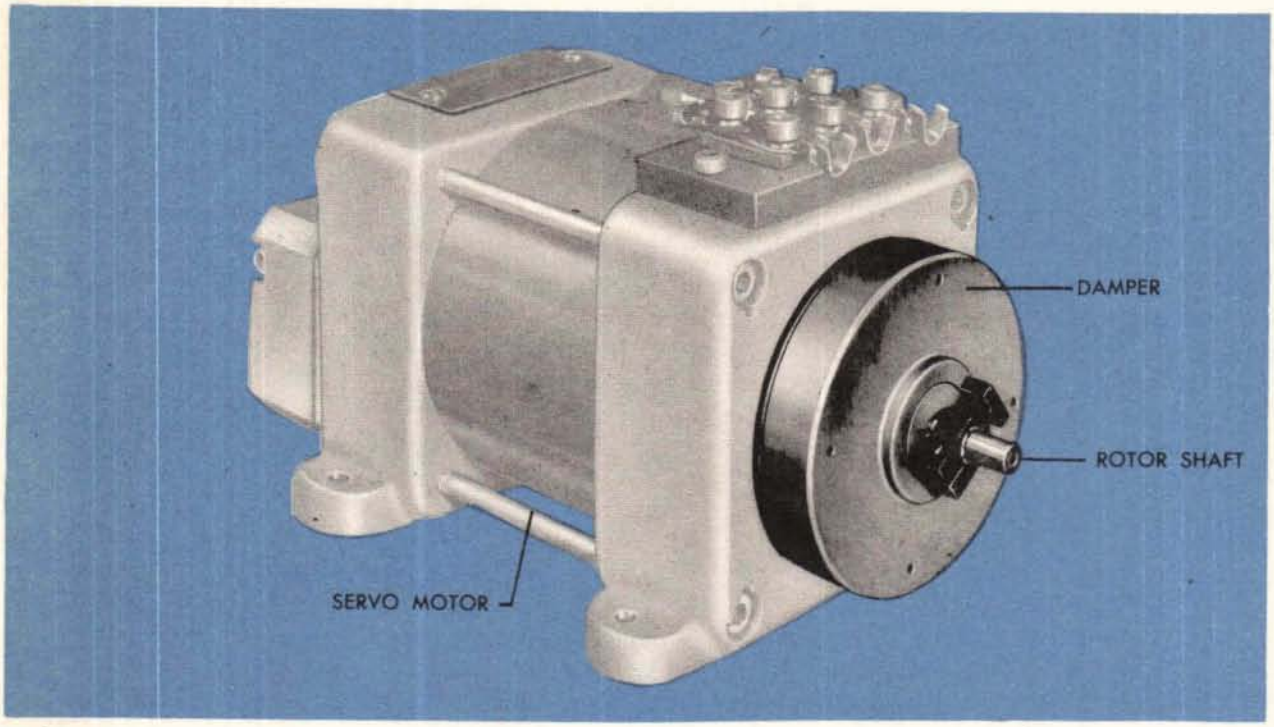
Such an error can be disregarded where the incoming signal reaches a certain value quickly and remains fixed for a considerable length of time, as it does in the case of Own Ship Speed, *So*.

The error can also be disregarded in cases where a constantly changing signal changes slowly, and the center contact arm is offset by only a small amount.

When the incoming signal changes at high velocity, and output readings must correspond exactly with input at every instant, as in the case of Relative Bearing, *B'r*, velocity lag error cannot be tolerated. To eliminate velocity lag, the magnetic drag is incorporated into a device known as a "compensator." Follow-ups having such a compensator are called compensated type follow-ups.



THE MAGNETIC DAMPER



In the section on Follow-up Controls it was mentioned that a magnetic damper is used to reduce the oscillations which occur when the motor reaches the point of synchronism.

The part played by a damper is best understood by considering why such a device is necessary at all. To do this, the nature of the oscillations between the contact points must be examined.

Oscillations between contact points

It has already been shown, in describing the magnetic drag, that because of a servo motor's inclination to keep turning once it has started to turn, the motor causes first one outer contact and then the other to swing over and touch the center contact after position of zero error has been reached. It has also been shown that the purpose of the drag is to limit this swinging to as few oscillations as possible (consistent with the general efficiency of the mechanism) in order to bring the motor to rest quickly.

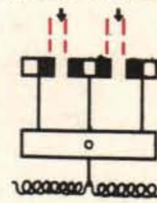
Theoretically, there should be no further movement of the servo motor after the drag has slowed it down, and the centering springs have brought the center contact arm to the position of zero error.

The motor should come completely to rest and no further oscillations should occur.

In practice, however, oscillations between the contacts are *not always completely eliminated* by action of the drag.

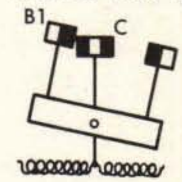
When the motor reaches the point of synchronism the first time, it overruns the point at high speed, and hence has a large amount of energy stored in its rotor, due to angular momentum. Upon being reversed, it crosses the point of synchronism with considerably less speed, and with considerably less energy in its rotor. This process is repeated. Finally, the rotor loses so much momentum that it has only sufficient energy to *drift* past the point of synchronism.

ONLY SMALL SPACE BETWEEN CONTACTS



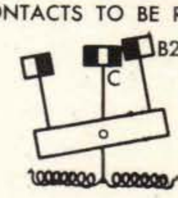
But it is only necessary for the rotor to rotate an outer contact arm slightly (just sufficiently to move it across the small space that normally separates an outer contact from a center contact) in order to cause the electric supply circuit to the motor to close. This amount of rotation the rotor is able to accomplish, even when it only drifts past the point of synchronism. When the opposite outer contact is brought up to the center, the motor drives again, in the opposite direction.

ROTOR TURNING VERY SLOWLY



The process may be repeated indefinitely, resulting in a series of very small oscillations just big enough to cross the space between the outer and center contacts.

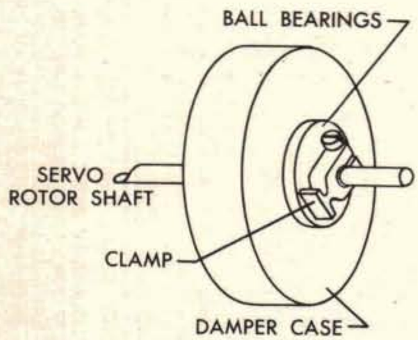
CONTACT B1 TOUCHES C AND ROTOR IS ENERGIZED JUST SUFFICIENTLY FOR CONTACTS TO BE REVERSED



In practice, these small oscillations occur in fairly rapid succession, and can best be described as a form of "jitters."

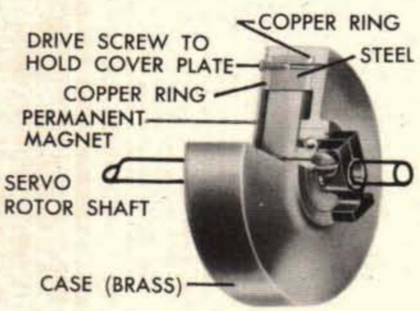
It is the business of the magnetic damper to supplement the action of the drag and to reduce this jittering. The combined efforts of both drag and damper are finally responsible for bringing the motor to a standstill at the point of synchronism, with oscillation between the contact points practically eliminated.

The magnetic damper consists of:



A brass case which is ball-bearing-mounted on the rotor shaft and *free to turn.* Inside the case is attached a heavy steel ring, on each side of which is a copper ring. When this weighted case is rotated, it has the inclination to keep turning, and therefore is called the "inertia weight" of the damper.

A permanent magnet (inside the case) which is *fixed* to the rotor shaft of the servo motor.



How it operates

1. When the servo rotor revolves, it rotates the permanent magnet.
2. The magnetic field around the magnet is rotated.
3. The lines of force in this magnetic field cut through the steel ring as the field moves past.
4. When this happens, a current is induced in the steel ring, and the two copper rings help to distribute this current evenly throughout the steel.
5. The induced current creates a magnetic field of its own.

As the rotor turns, the magnet field and the field of the steel ring react together in such a way that the ring tends to be pulled around in the direction in which the magnet is moved. And since the ring is attached to the case, the whole case turns. In other words, the rotating magnet exerts a torque on the case which tends to make the case revolve in the same direction as the magnet.

A magnetic force coupling between the magnet and the case is therefore produced by turning the magnet.

The slightest movement of the magnet will set up this magnetic couple.

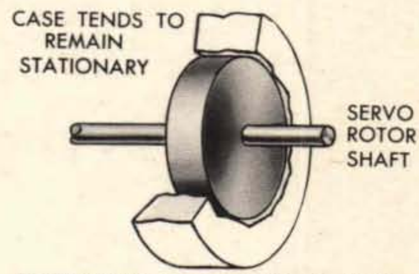
Elimination of small oscillations

Whenever the rotor speed has been so reduced that it has only sufficient energy to drift across the point of synchronism, the case of the damper has become stationary.

The damper case, being comparatively heavy and stationary, is not easily rotated. The inclination of the case to remain at rest once it has stopped acts as a brake on the rotor whenever the rotor starts to turn.

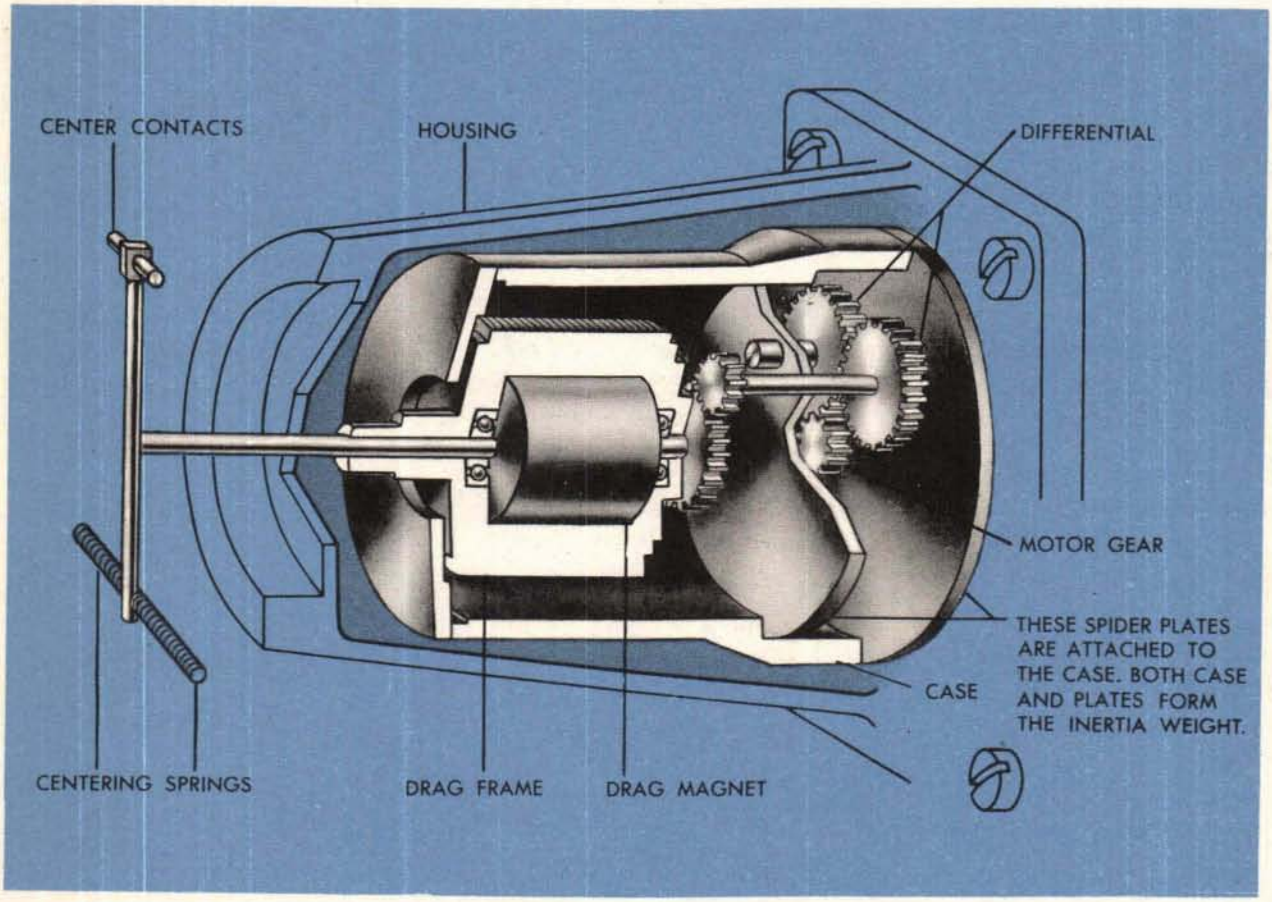
The small amount of energy made available to the rotor, when the contacts momentarily touch as they drift across the point of synchronism, has to overcome the tendency of the damper case to remain stationary, and the rotor comes to a standstill quickly.

All oscillations, therefore, soon cease and the motor is brought to *rest at the point of synchronism,* the outer contact arm being at the position of zero error.



STATIONARY CASE TENDS TO PREVENT MAGNET BEING ROTATED

THE COMPENSATOR



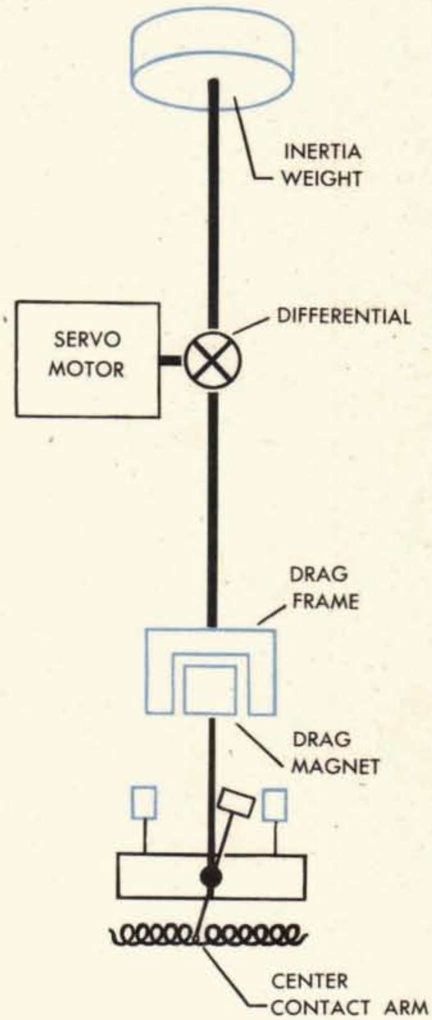
It has been shown that the use of a magnetic drag introduces a velocity lag error between the input and the output of a follow-up control while the signal is changing, and that such an error becomes too great to be permitted when a signal comes in at a high velocity.

The velocity lag error is eliminated by a "compensator," which consists of a magnetic drag and an inertia weight, both of which are driven by the servo motor through a differential.

The motor drives one end gear of the differential and the drag is driven by the other end gear. The spider of the differential, is attached to a comparatively heavy case to form the inertia weight.

Operation

The compensator can be represented schematically as shown here.



When the servo motor starts to drive, the inertia weight tends to remain at rest. One side of the differential rotates the frame of the drag, and this rotation causes the drag frame to be coupled to the magnet by a magnetic force coupling.

The magnetic force coupling applies a torque to the drag magnet, and since the magnet cannot be pulled around more than a few degrees, there is a resistance to the rotation of the frame.

The side of the differential which rotates the frame of the drag must drive against this resistance.

This being so, the other side of the differential must drive with an equal force. And since there is nothing holding the inertia weight stationary, this force starts the weight rotating.

The inertia weight gathers speed under this applied torque, and if the servo motor continues to drive at constant speed, the inertia weight gaining momentum quickly approaches the speed of the motor.

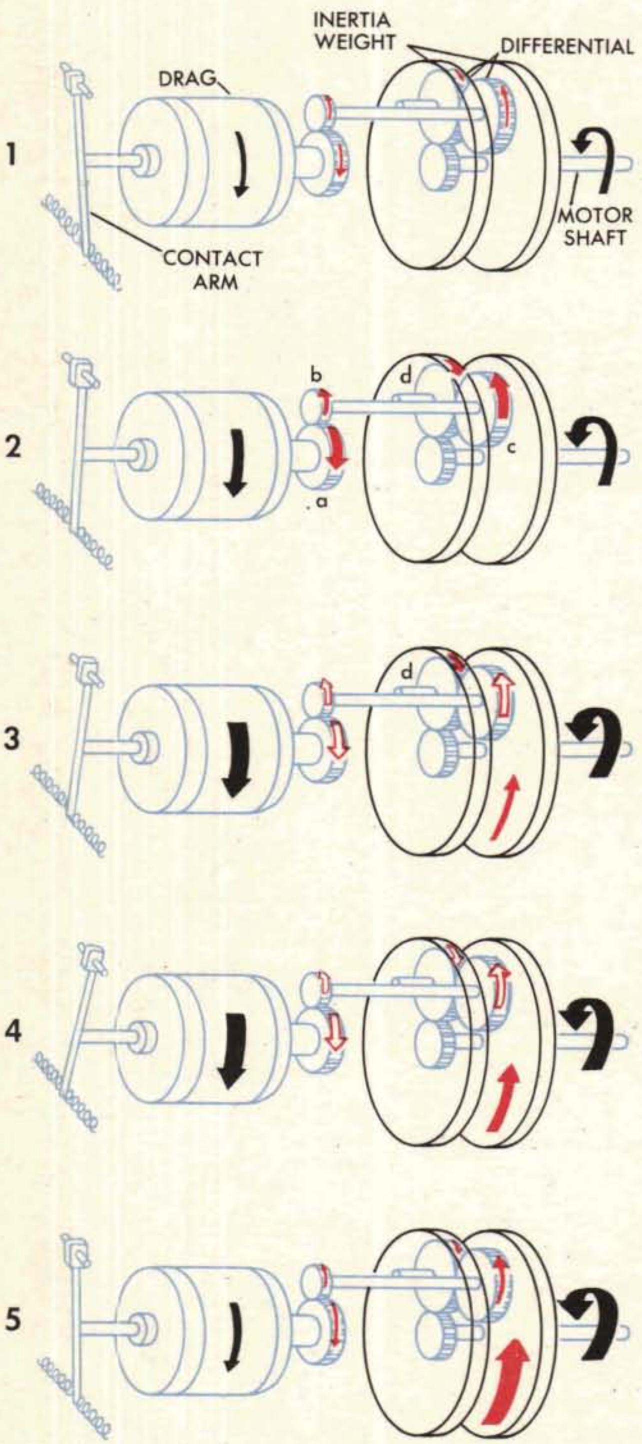
Now the total output of the differential can only equal the input. That is, the speed of the drag frame *plus* the speed of the inertia weight can only equal the speed of the motor. Therefore, as the inertia weight gains speed, the drag frame must lose speed. This it does, until it comes almost to rest.

As the drag frame loses speed, the torque exerted on the drag magnet decreases.

Immediately, the centering springs act to bring the center contact arm back to its center position, and the contact assembly comes back to the position of zero error.

THEREFORE, WHILE A SIGNAL IS CHANGING AT CONSTANT SPEED, THIS FOLLOW-UP CONTROL WILL OPERATE WITHOUT LAG ERROR.

COMPENSATOR and CONSTANT SPEED SIGNAL



The action of the compensator, during the course of a signal which changes at constant speed consists of five steps:

1 The motor starts to drive, and driving through the differential rotates the frame of the drag.

2 As the motor picks up speed, the drag frame picks up speed and the torque exerted by the frame on the drag magnet increases. The drag magnet is prevented from rotating beyond a limited distance by the pull of the centering springs. The effect of the increased torque on the drag magnet therefore reacts back through the drag in the form of a force which tends to reduce rotation of gears *a, b, c,* and *d*.

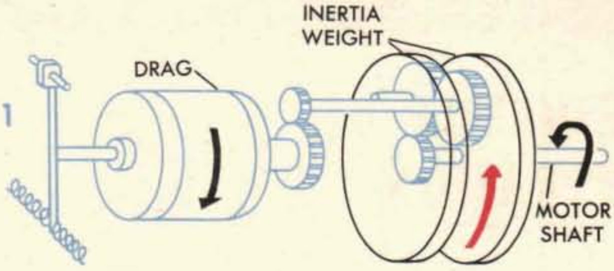
3 The motor is driving at constant speed. When the drag acts to slow down the rotation of the gearing, gear *d*, being in mesh with the motor gear, is carried around with the motor gear instead of rolling on it. Since the shaft of gear *d* is mounted in the inertia weight, this action causes the weight to be rotated.

4 As the motor continues to drive, the inertia weight picks up speed, and tends to reach a speed corresponding to the speed of the motor. As this occurs, the speed of rotation of the gearing, and hence of the drag frame, decreases.

5 With the reduction in speed of the drag frame, and a corresponding reduction in the torque exerted on the drag magnet, the centering springs bring the center contact arm to position of zero error.

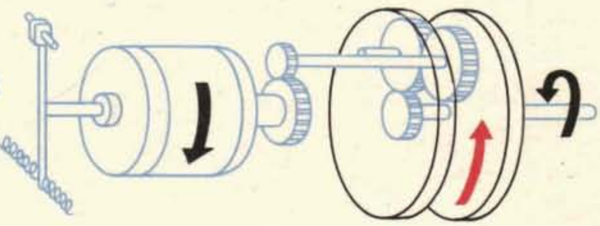
COMPENSATOR and ACCELERATING SIGNAL

If the signal does not change at a constant speed but *accelerates* as it comes into the follow-up control, the action of the compensator is somewhat different:

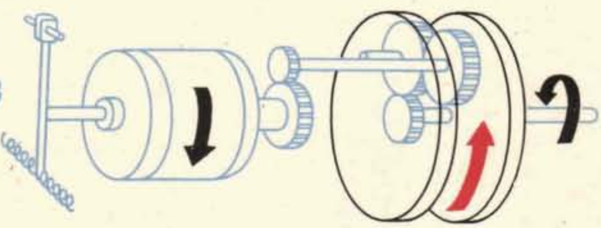
1


1, 2 Since the signal accelerates, the servo motor accelerates. The inertia weight, however, being comparatively heavy, tends to hold to its own speed, and is not easily speeded up.

As the differential output must equal the input, the increase in speed of the motor acts through the side of the differential which drives the drag frame, making the frame rotate faster.

2


3, 4, 5 Because of the tendency of the inertia weight to "take its own time," the continually increased speed of the motor (due to acceleration) operates where it finds least resistance: on the frame of the drag.

3


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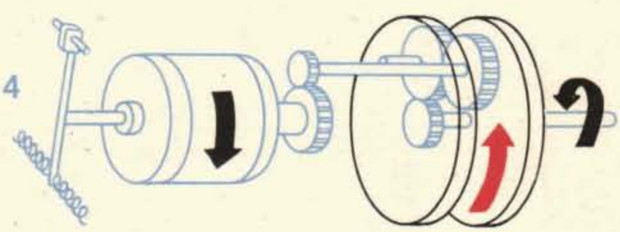
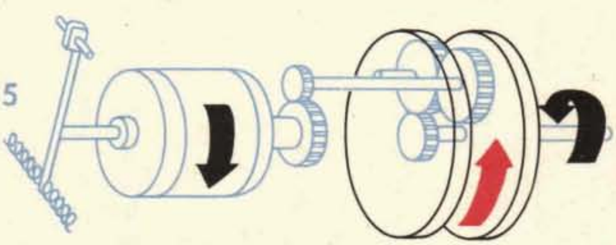


The inertia weight never attains the speed necessary to allow the drag to slow down sufficiently to permit the center contact arm being brought to point of zero error.

As a result, the contact arm remains displaced from center throughout the period of the signal acceleration, the displacement being proportional to the acceleration of the drive. This, of course, introduces an error into the position of the powered shafting (output) proportional to the acceleration of the drive.

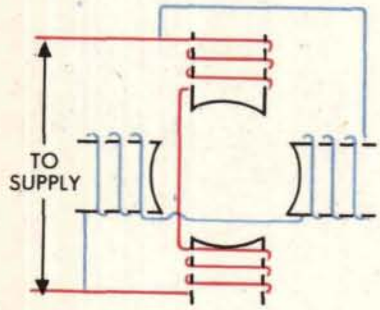
5


Proper proportioning of the parts of the compensator reduces this error to a point where it becomes negligible.

SERVO THEORY

PRINCIPLE OF OPERATION

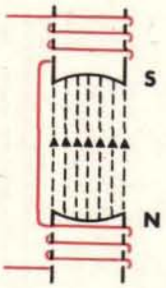
Magnetic flux



Servo motors used in the fire control instruments are of the induction type, designed to operate on single phase, 60 cycle, alternating current.

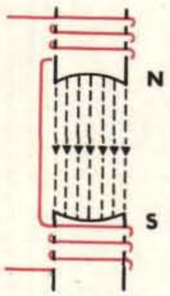
To understand how the rotor in this type of motor is made to revolve, several factors must be considered:

The stator, or field winding, has four poles.

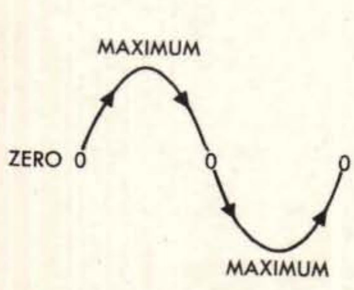


When current is passed through the stator coils, lines of force (magnetic flux) pass between opposite poles.

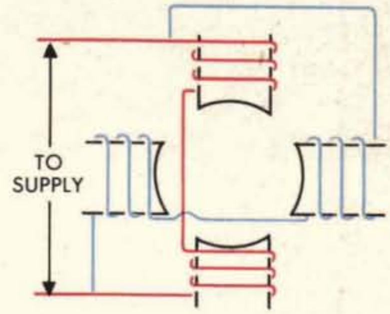
Considering only one of the coils, the direction of the flux at a particular instant can be shown as passing from the *N* pole to the *S* pole.



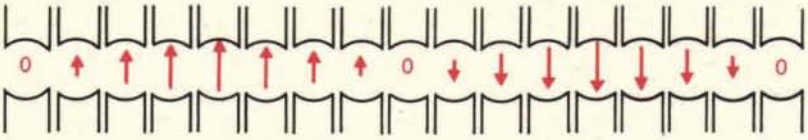
When the alternating current reverses direction, the poles are reversed, and the direction of the flux reverses.



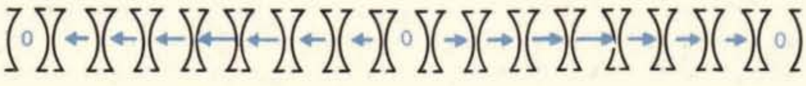
Now, although the current reverses direction rapidly (120 times per second), it is incorrect to consider it as reversing in a series of sharp, clear-cut jerks. It is more correct to consider it as growing in intensity, in one direction, and then fading out to zero, growing in intensity in the opposite direction, and again fading out to zero—as indicated in the graph. The magnetic field can be considered as growing in intensity in one direction and fading gradually to zero, and then doing the same thing in the opposite direction.



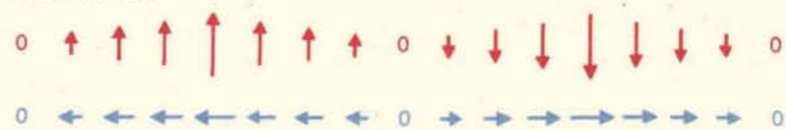
Schematically these pulsations may be represented by a series of arrows between the poles:



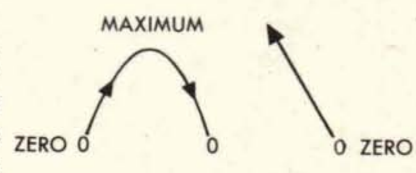
Pulsations between the second set of poles (which lie at right angles to the pair just considered) may be shown in the same way:



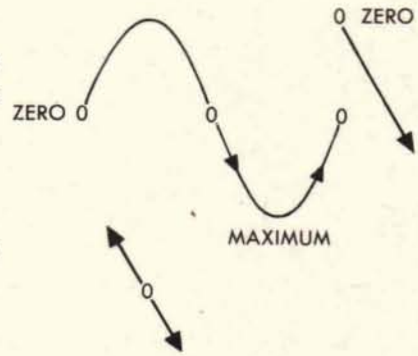
Considering the two sets of poles together with both coils supplied from the same source, the pulsations in the magnetic field between the four poles of the servo motor may be shown as follows:



The direction in which the resultant effect of these two fields operates, at any instant, can be shown by adding any two of the components shown here, and tracing the diagonal of the parallelogram obtained:

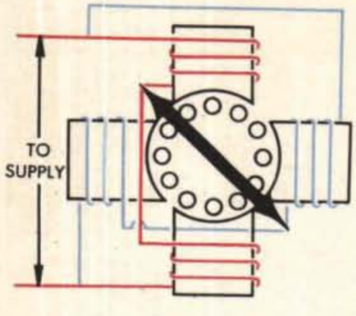


Adding these resultants together, it is found that the total effect of the current in the coils is to create a field which builds up in intensity in one direction, as the current builds up to its maximum, and then fades to zero as the current decreases to zero - - -



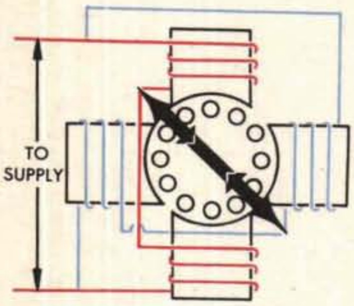
- - - - after which the field builds up in intensity in the opposite direction, as the current reverses, and again fades to zero as the current completes the cycle.

The lines of force, or flux, act along a straight line, and this stator field can be termed an oscillating, or pulsating, field.



How the stator field affects the rotor

When a rotor is placed in a pulsating field, the lines of force cut through the conductors on the rotor, first in one direction and then in the opposite. This varying flux has the same effect as if the rotor conductors themselves were moved through a magnetic field. An electrical pressure is induced in the conductors. Since the ends of the conductors are joined to common end rings, currents flow around the closed circuits thus provided.



The rotor field

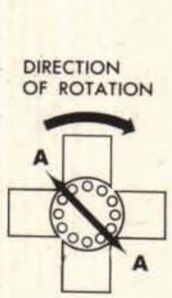
Now, according to Lenz's law of physics, voltage induced in a conductor sets up a current whose magnetic field always opposes any change in the existing magnetic field. The magnetic field set up by the current in the conductors of the rotor therefore opposes changes in the magnetic field set up by the current in the stator coils of the motor. In other words, each time the action of the field due to current flowing through the stator coils can be represented as building up in one direction, the action of the field due to current induced in the rotor can be represented as building up in the opposite direction.

Characteristics of the two fields

It will be noted that both stator and rotor fields build up (and collapse) along a straight line, which passes through the center of the rotor.

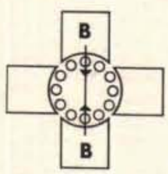
Another characteristic of these fields is that the stator field and the rotor field do not build up evenly at the same time. The field due to current in the stator coils, reaches peak intensity, and is actually collapsing, before the field due to current induced in the rotor reaches peak intensity. That is, the induced current lags the applied current.

Since the resultant flux in both the stator and rotor fields acts along the same straight line through the center of the rotor, however, no force is produced in the form of a torque which will make the rotor turn.

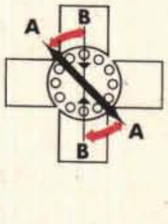


Making the rotor turn

Suppose the rotor of the motor is now given a spin by hand in the direction shown. The path taken by the resultant flux of the stator field remains in the same position—indicated here by the line *AA*. But since the induced current lags the applied current, it means that the current induced in conductors of the rotor, as these conductors move through the path taken by the flux of the stator field, does not reach peak until the conductors have *passed* line *AA*.



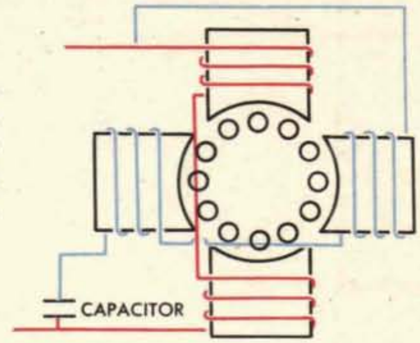
Here the induced current in conductors which have just passed through *AA*, reaches peak intensity at *BB*. The resultant flux of the rotor field, therefore, no longer acts along the same straight line as taken by the flux of the stator field, but along a line which lies at an angle to it.



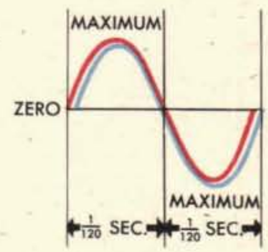
Under such conditions, attraction occurs between the poles of the two fields, as indicated here, and this results in a torque being applied to the rotor, causing it to keep turning.

The effect of the capacitor

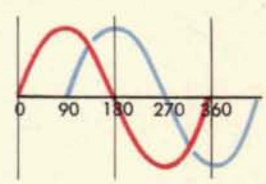
A capacitor is employed in order to make the rotor of an induction type motor, such as a servo, start turning. That is, a capacitor is used to do the job done by hand in the instance just described. To understand how a capacitor can cause a motor to start, consider the action of the lines of force, or flux, in the stator when no capacitor is present.



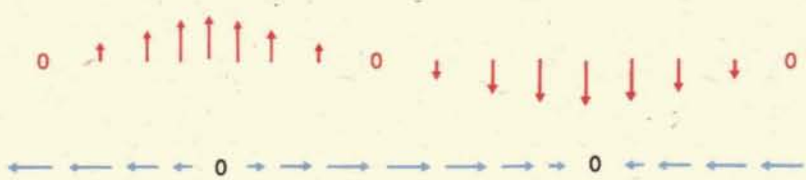
Without a capacitor, the current in the two stator coils builds up in the same direction simultaneously, reaching a peak value at the same instant. That is, the current in one stator coil is "in phase" with the current in the second stator coil, with respect to time.



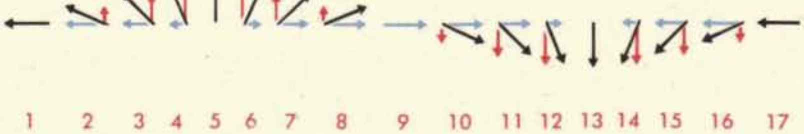
When a capacitor is used, the current in one coil reaches a peak *before* the current in the second coil, in the manner indicated here. That is, the currents are approximately 90° "out of phase" with respect to time.



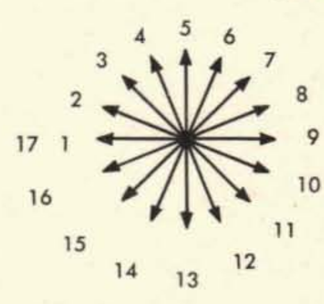
Using arrows again, the pulsations between the poles of the stator coils can now be schematically represented as follows:



Now note that when the current is a zero in one coil, it is at a maximum in the other coil. By adding components and tracing resultants, the following picture is obtained of the action of the stator field during the period of one current cycle (1/60 sec.).



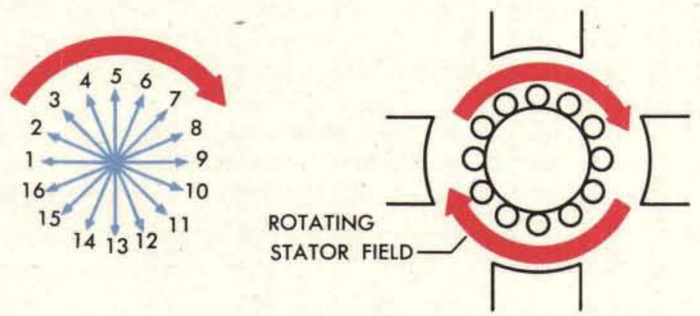
These resultants indicate how the path taken by the resultant flux of the stator field *changes position* from instant to instant. The stator field still remains an oscillating field, pulsating along a straight line which passes through the center of the rotor, but the position of the line now keeps changing.



For instance, the path along which the resultant flux acts, can first be indicated in position (1), and then in position (2), and so forth. Taking these positions in succession, it is found that they rotate through 360°. In other words, the stator field now not only oscillates along a straight line through the center of the rotor, but *also rotates.*

The rotating stator field and the induced current lag both act to make the rotor turn

Placing a capacitor in the circuit, therefore, has caused the stator field to rotate. In this way, a torque is developed which starts the motor running.



As the field rotates, the lines of force cut through the conductors of the rotor, inducing voltages in the conductors. And since the conductors are joined to common end rings, currents flow in these conductors.

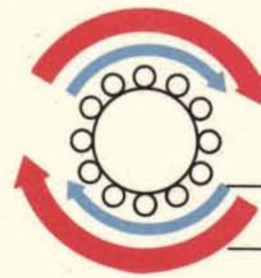
Also, since current induced in the conductors at any instant lags the current in the stator coils, it means that at each instant a condition exists such as described previously, where the resultant flux of the induced field acts at an angle to the path taken by the resultant flux of the stator field. That is, at the proper instant, each conductor has a force acting upon it (due to attraction between the poles of the stator and rotor fields) which takes the form of a torque, pulling the conductor around.

Once started, induction-type motors quickly develop maximum torque under normal load.

If too small a capacitor is used for a motor of a given size, sufficient starting torque is not developed under normal load. If too large a capacitor is used, the starting torque will be large, but torque will diminish when the motor picks up speed. This is because too powerful a starting torque results in the poles of the stator and rotor fields becoming separated by a considerable distance, and this, in turn, results in the repulsion between the poles being diminished.

With any given motor, use only the capacitor specified.

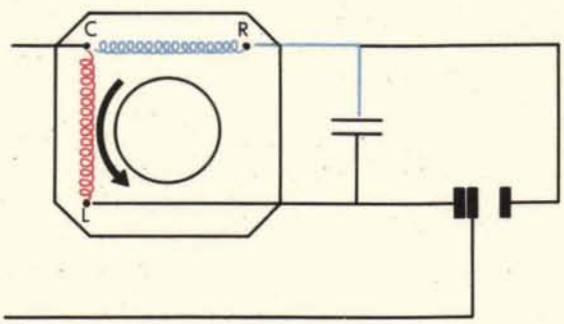
How the rotor revolves

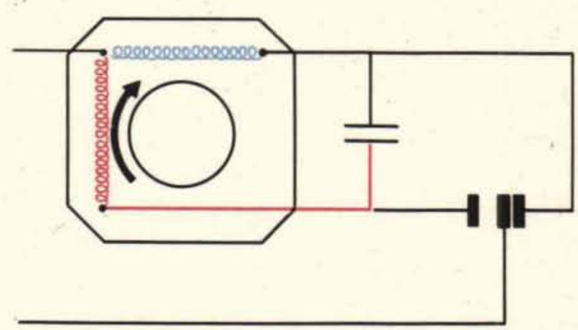


The other requirement of the follow-up motor is that it will drive in the direction required.

The force exerted on the conductors always acts to pull the conductors in the direction in which the stator field is moving. By controlling the direction of rotation of the stator field, the direction of rotation of the rotor is controlled.

Looking back to page 345, it will be seen that with the capacitor in the circuit as shown, the flux of the blue coil reaches a maximum value at 1, while the flux in the red coil does not reach its maximum value until 5. In other words, the flux in the blue coil is "leading" that in the red coil.





Now, if the motor connections are changed so that the blue coil is supplied directly while the red coil is supplied through the capacitor, the conditions will be changed. That is, the flux in the red coil will now lead that in the blue one, and the field will rotate in the opposite direction.

This explains how the follow-up is able to control the direction of rotation of the servo motor by shifting the capacitor from one part of the circuit to the other.

SECTION 6

ARMA MECHANISMS

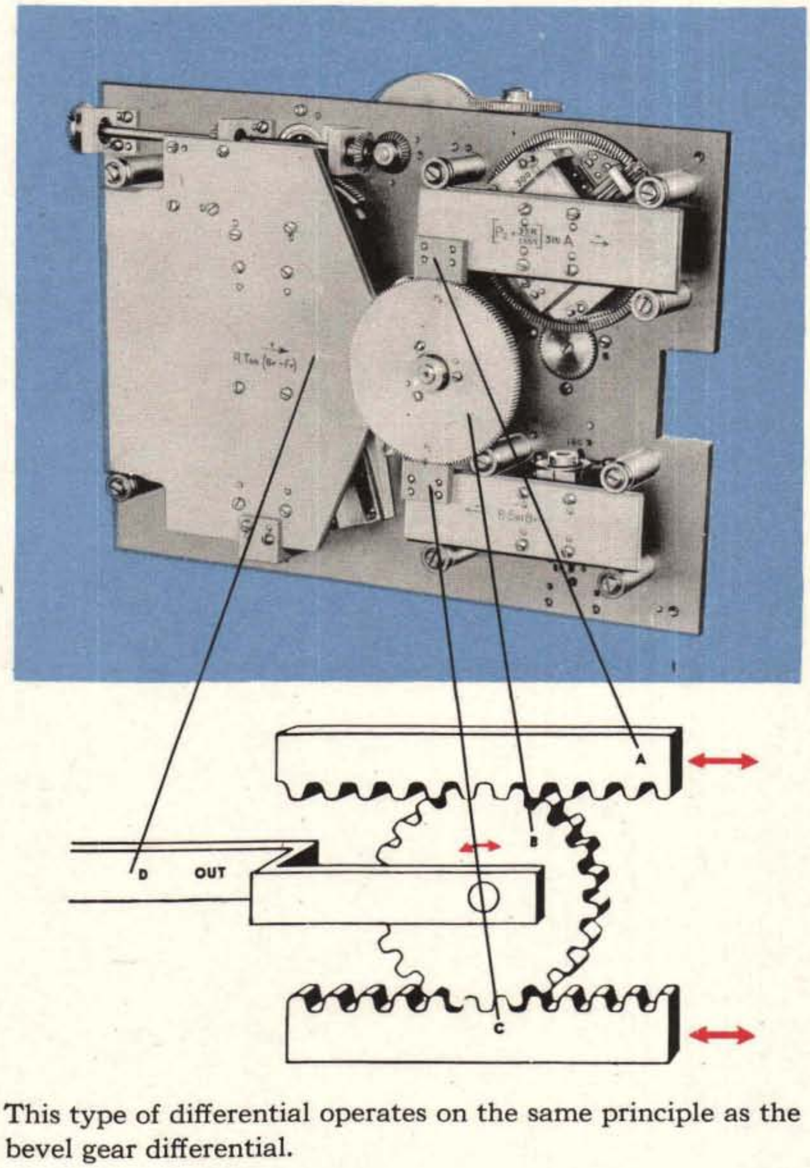
The Units described in this section are used in the ARMA Torpedo Data Computers.

The principles of operation of several of the units have already been explained in detail in describing such Ford mechanisms as differentials, integrators, and component solvers. The reader is, therefore, assumed to be fairly familiar with these principles, and the descriptions in this section have been made as brief as possible.

To a great extent the concise explanations published in the technical literature of the manufacturer have been used.

DIFFERENTIALS

LINEAR RACK AND PINION differential



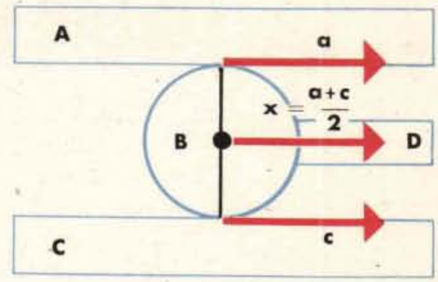
This type of differential operates on the same principle as the bevel gear differential.

Inputs to this differential, however, are not made by rotation of end gears, but by straight line movement of the two racks, *A* and *C*.

The output is proportional to the linear movement of pinion *B*.

Suppose both racks are moved the same distance, in the same direction, at the same time. The pinion B will not roll, because the torque applied by rack A to the top of the pinion is equal and opposite to that applied by rack C to the bottom of the pinion.

Since the pinion does not turn, it is carried forward the same distance as the racks are moved.



Suppose rack A is moved by an input a, and rack C is moved by an input c. The total input to the differential will be $a + c$. Pinion B will move a distance x. If a and c are equal, x will be equal to both a and c, or $x = \frac{a+c}{2}$.

Movement of pinion B therefore represents half the sum of the two input movements.

Pinion B positions an output mechanism which transmits the output motion to carriage D.

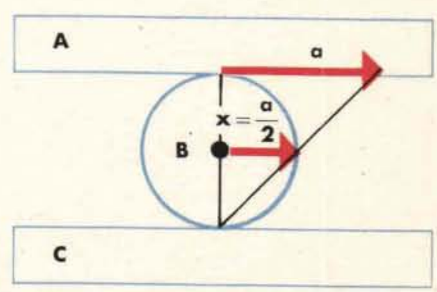
With 1:1 gear ratio between the output mechanism and the gear which actually moves carriage D, one half the sum of the inputs $\frac{a+c}{2}$ positions the carriage.

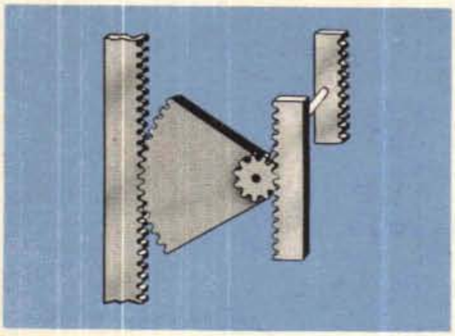
By using a 2:1 gear ratio, however, the sum total of the inputs $a + c$ positions the carriage.

If rack A moves an amount a in the direction shown and rack C remains stationary, pinion B will roll on rack C, and its center will move half as far as rack A is moved. This is explained by the ruler and cylindrical drinking glass experiment shown on page 41.

B will move through a distance x, which is equal to $\frac{a}{2}$.

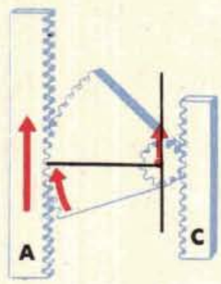
With 2:1 gearing, the output can be doubled, so that movement $\frac{a}{2}$ by the pinion results in an output value a positioning carriage D.





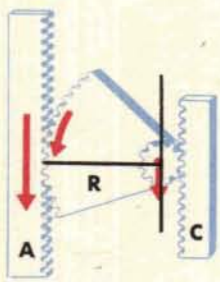
LINEAR RACK AND

In this differential, as in the linear rack and pinion differential, inputs are represented by straight-line movements of two racks. Instead of the output corresponding to the movement of a pinion, however, it corresponds to the movement of a special type of follower which consists of a sector gear carrying a pinion on one side. The sector gear and pinion are in one piece; the pinion does not revolve by itself. Any movement of the sector gear moves the pinion, and vice versa.



If rack *C* remains stationary, and rack *A* moves upward, two things occur:

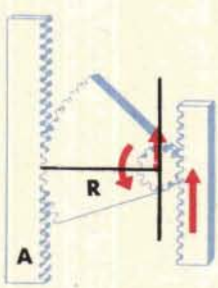
1. The sector gear rotates in an upward direction, following the movement of the rack.
2. The pinion, rotated by the movement of the sector gear, also moves upward—rolling on rack *C*.



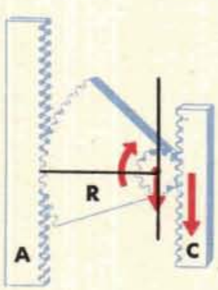
Conversely, if rack *A* is moved downward, the pinion will again roll on rack *C*, this time downward.

No matter how far the pinion is moved along rack *C*, it will always remain at the same distance from rack *A*, because the teeth of the sector gear are on the circumference of a circle whose center is also the center of the pinion. The distance between the center of the pinion and rack *A* is always equal to the radius, *R*, of this circle.

Any movement of rack A, therefore, results in a straight line movement of the pinion in the same direction as the rack is moved.



If rack *A* is held stationary and rack *C* is moved upward, the sector gear will be rotated counterclockwise, but the pinion will be moved upward in the same direction taken by the rack.



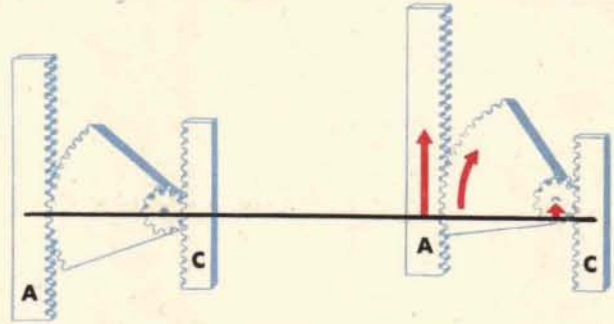
In the same way, if rack *C* is moved downward, the pinion will be moved downward.

Any movement of rack C, therefore, results in a straight line movement of the pinion in the same direction as the rack is moved.

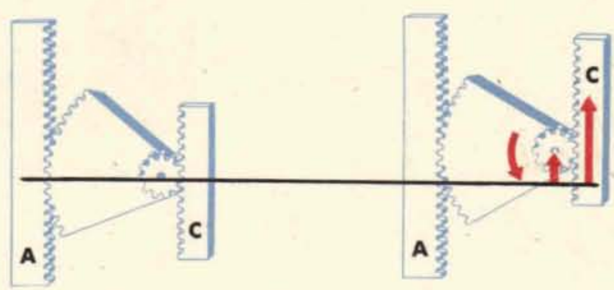
SECTOR GEAR differential

The motions of rack *A* and rack *C* do not affect the movement of the pinion equally. A given amount of movement on *A*, for example input *X*, may only cause the pinion to move a short distance, while the same amount of movement on *C* will cause the pinion to move through a comparatively long distance.

However, the distance the pinion is moved by rack *A* is *proportional* to the input on *A*, and the distance the pinion is moved by rack *C* is *proportional* to the input on *C*.



INPUT MOVES ONLY RACK A

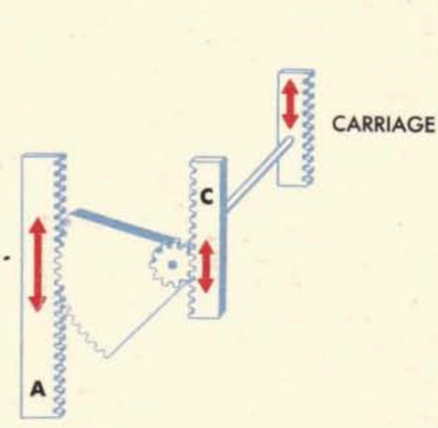


INPUT MOVES ONLY RACK C

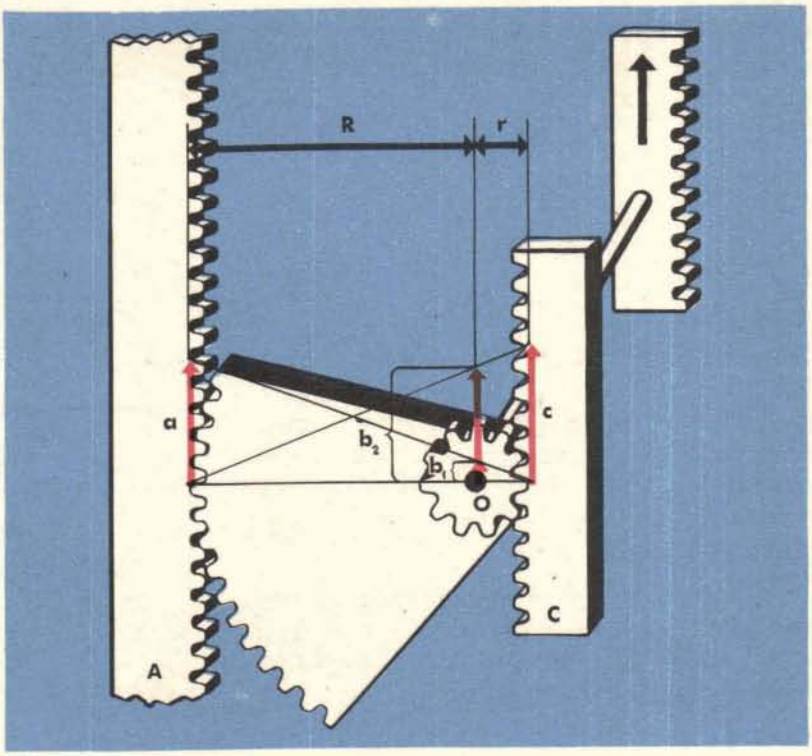
When both rack *A* and rack *C* are moved, therefore, the amount the pinion is moved is proportional to the sum or difference of the inputs on *A* and *C*.

In this way, movement of the pinion corresponds to the output of the differential.

If the pinion is attached to a carriage, any movement of the pinion will move the carriage. The carriage will move an amount proportional to the sum of the inputs of the differential.



Movement of follower in the linear sector gear differential



The amount which the pinion is moved when the racks are moved is computed as follows:

Let 0 be the center of the pinion. Let R be the radius of the sector gear, and r the radius of the pinion.

Assume that the movement of 0 due to the displacement a of rack A is b_1; and that the movement of 0 due to displacement c of rack C is b_2. The total movement of 0 is equal to the sum of the two components, or $b_1 + b_2$.

To find the values of b_1 and b_2, consider the two pairs of triangles shown. One pair consists of the triangle with side a and base $R + r$, and the triangle with side b_1 and base r; the other pair consists of the triangle with side c and base $R + r$, and the triangle with side b_2 and base R.

In the first pair of triangles, $\frac{b_1}{r} = \frac{a}{R+r}$, or $b_1 = \frac{ar}{R+r}$

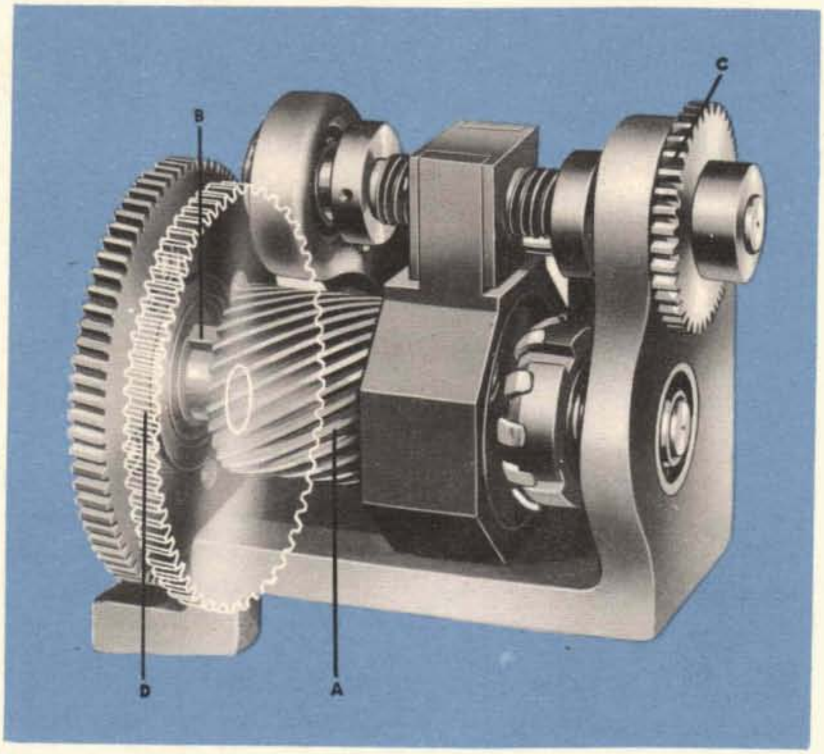
In the second pair of triangles, $\frac{b_2}{R} = \frac{c}{R+r}$, or $b_2 = \frac{cR}{R+r}$

Adding the two equations gives:

$$b_1 + b_2 = \frac{ar}{R+r} + \frac{cR}{R+r} = \frac{ar + cR}{R+r}$$

Since both R and r are constants, the output of the differential, $b_1 + b_2$, is proportional to the sum of the inputs a and c — using the proper proportionality constants.

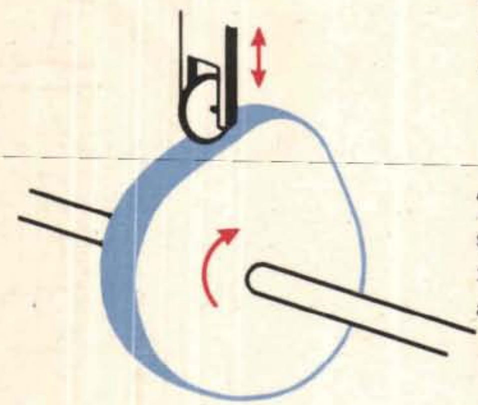
HELICAL GEAR differential



Here is an unusual application of the differential principle. The helical pinion *A* can be moved axially on shaft *B*. This movement is accomplished by turning the input gear *C* which rotates a threaded shaft on which is mounted a carriage. This carriage is fastened to the pinion *A* and carries the pinion with it as it moves along the threaded shaft.

The pinion *A* meshes with a helical gear *D* so that as the pinion moves axially, it is also turned an amount which depends upon the magnitude of the axial movement. In this respect it acts like a screw. In addition the pinion receives a rotary input from the helical gear *D*. The output shaft *B* receives the added motions. The output on shaft *B* is always proportional to the input at gear *C* plus the input at gear *D*.

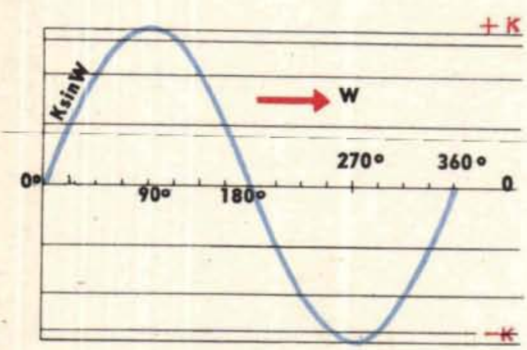
CAMS

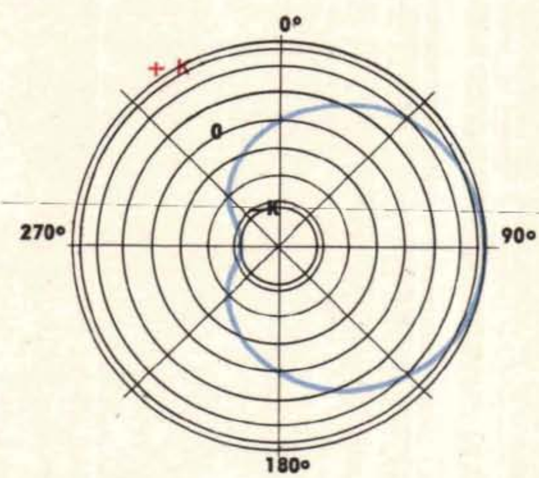


The simplest form of cam is a wheel with some sort of irregularity on its outside edge (periphery). A follower rides on the wheel and reproduces the irregularity in a reciprocating motion. A cam of this type is shown here.

The cam can be designed so that the follower will move to satisfy a mathematical function of the cam input. For example, it is possible to obtain a follower movement equal to $K \sin W$, as represented in the graph below, if K is a constant.

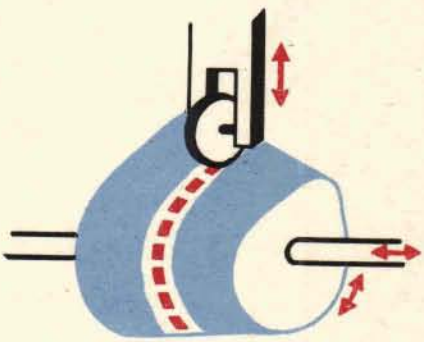
Such a cam is constructed with a gradually changing radius, so that the periphery of the cam causes the follower to move up and down with the correct motion in relation to the turning of the cam. This cam is shown in the figure below. It is nothing more than the curve of the graph wrapped around a circle.



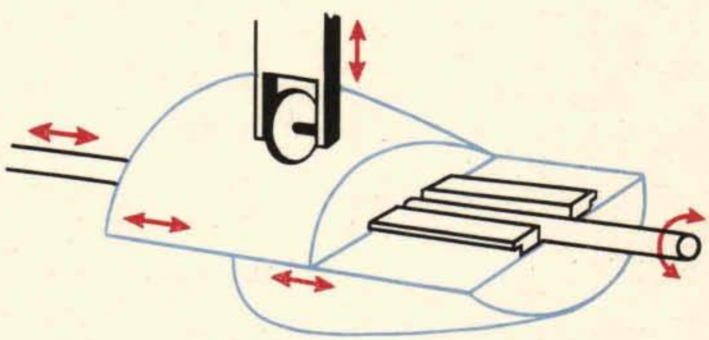


If a cam follower is to travel along different paths with changes in setting, several cams may be provided, so that selection of the proper cam produces the desired follower motion. A set of cams permits the use of another variable quantity.

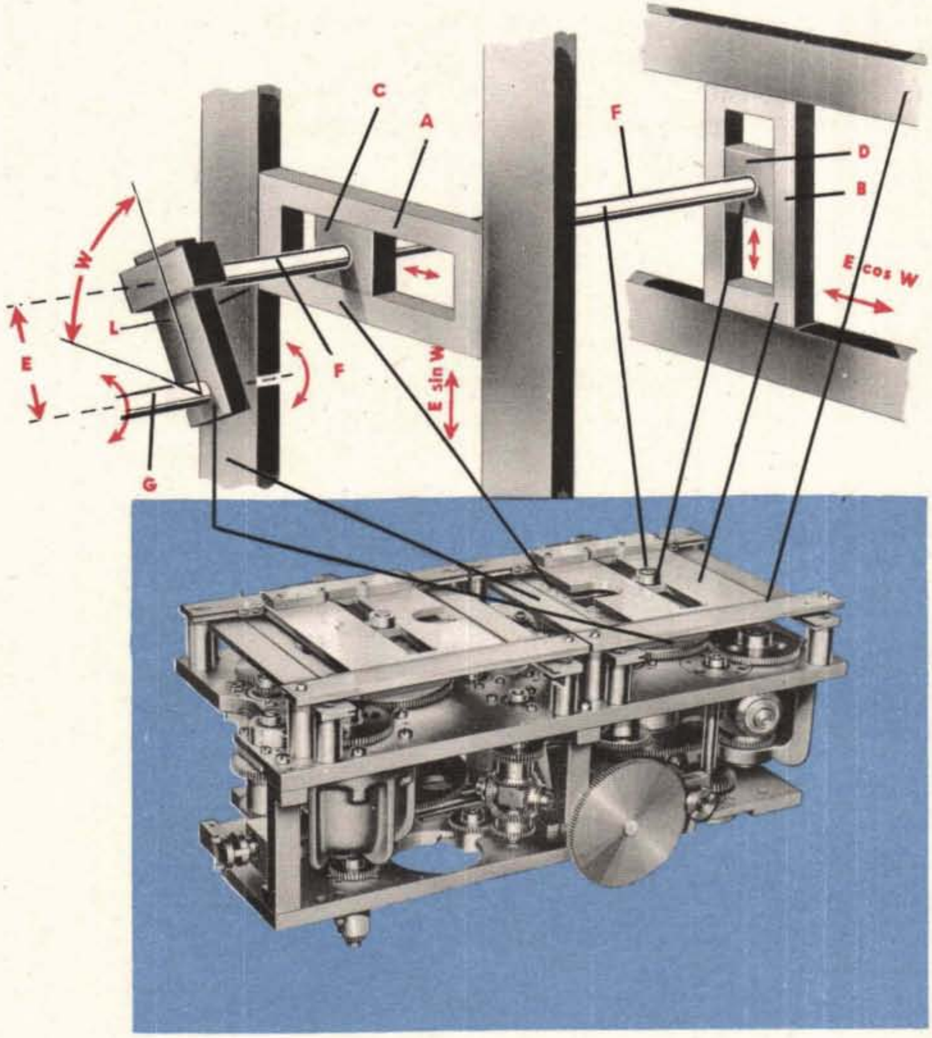
A single three-dimensional cam, as shown here, is an improvement on the set. The contour in contact with the roller is determined by the longitudinal position of the cam, instead of by changing cams. The third variable is introduced here by the axial positioning of the shaft.



The three-dimensional cam is sometimes used in a special form. The cam is split so that the two halves may be moved relative to each other. The split introduces an adjustment which is equivalent to providing a set of three-dimensional cams, any one of which may be selected depending upon the position of the two cam halves.



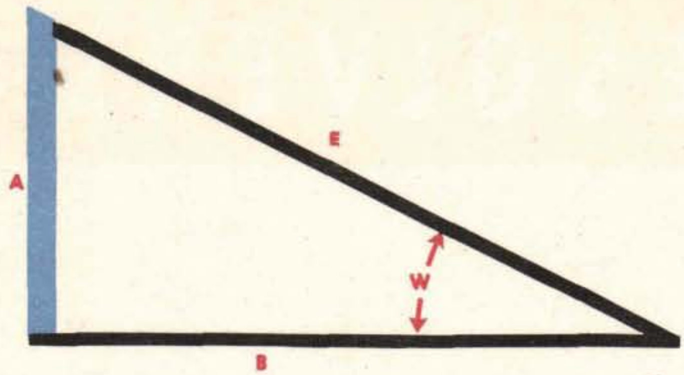
RESOLVERS



The inputs to this resolver consist of a given quantity and an angle which set up a vector. It is the job of the resolver to break down, or "resolve" the vector into two components at right angles to each other.

Let *E* be the given quantity. This can be set into the mechanism by varying the length of arm *L*.

Let *W* be the angle. This can be set in by rotating arm *L* the required number of degrees from the horizontal.



The resolver has two sliding carriages, *A* and *B*, which move in directions at right angles to each other. That is, carriage *A* moves up and down, whereas carriage *B* moves from side to side. The position which each carriage takes depends upon the position of the pin *F* and hence the blocks *C* and *D*. The pin is free to rotate in each of the blocks *C* and *D* which may travel in the slots of carriages *A* and *B*.

When the input shaft *G* rotates, pin *F* moves along an arc whose radius is *E*. Due to movement of pin *F*, the block C moves to a new location. However, in moving the block *C*, it is found that it can slide from side to side freely in the carriage *A*. Although it is not restricted in its side-to-side motion, the up-and-down motion of the block causes the carriage *A* to move up and down.

The block *D* also has the same movement as block C but it is permitted to slide up and down in the carriage *B*. Therefore, since the side-to-side motion of *D* is restricted, the carriage B must move from side to side with the block.

From the right triangle formed by *E*, *A* and *B*:

$$\sin W = \frac{A}{E} \qquad \text{or } E \sin W = A$$

$$\cos W = \frac{B}{E} \qquad \text{or } E \cos W = B$$

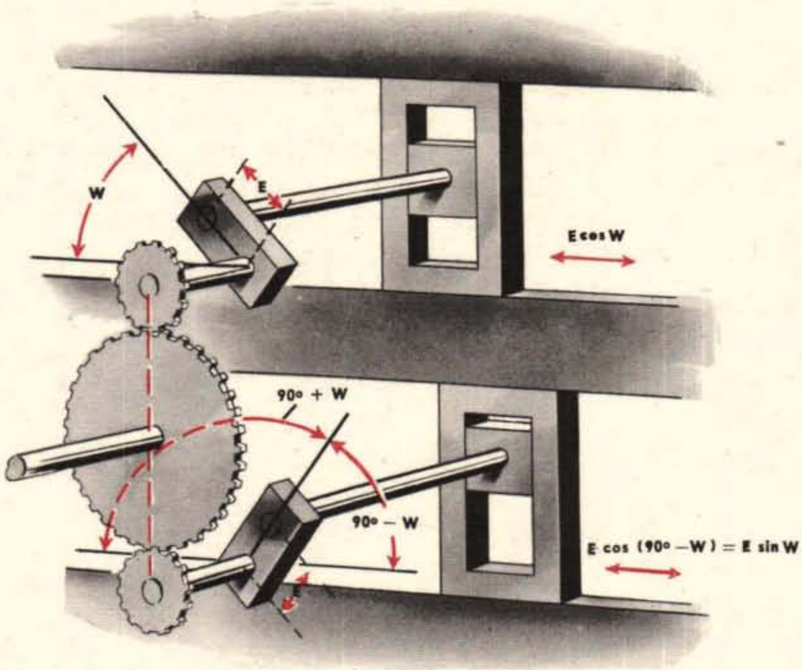
Any position of the arm *L* of the resolver determines some angle *W*. The carriage *A* moving up or down gives a position which determines *E* sin *W*, while the motion of carriage *B* moving from side to side gives *E* cos *W*.

A simplified form of resolver has an arm *E* which is not adjustable. This variation changes the outputs to cos *W* and sin *W* if the design is such that *E* may be used as equal to unity.

OTHER TYPES of RESOLVERS

A variation of the resolver is shown here. In this device there are two separate arms, which are always in positions 90° apart, and a carriage for each which moves from side to side. Each carriage will produce the cosine component of the angle between the arm and the horizontal. However, when the upper arm is at an angle W the lower arm is at the angle $90°-W$, as shown.

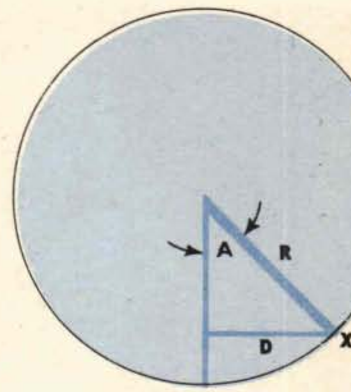
Since $\sin W = \cos (90°-W)$, the lower carriage not only gives $E \cos (90°-W)$, but also $E \sin W$. The upper carriage gives $E \cos W$. This variation of the resolver is used when it is desired to have the two carriages move in the same direction.



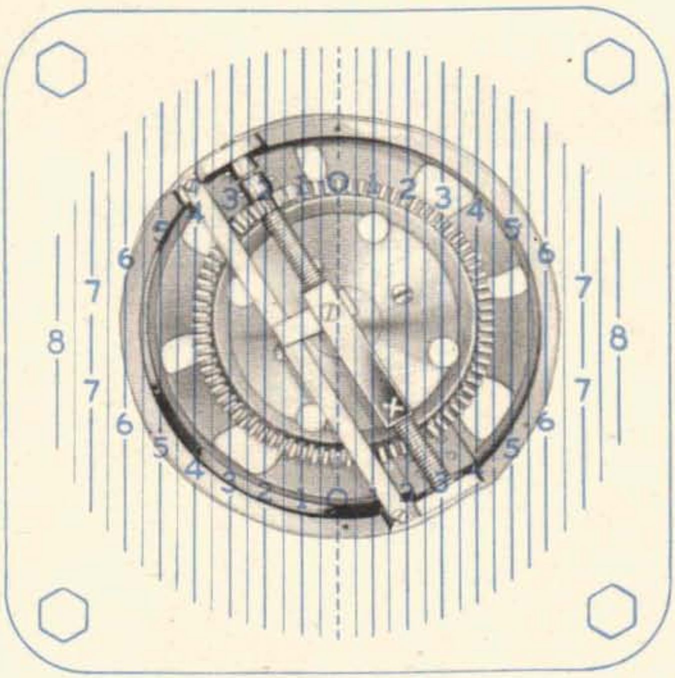
Another variation of a resolver uses the simple trigonometry equation:

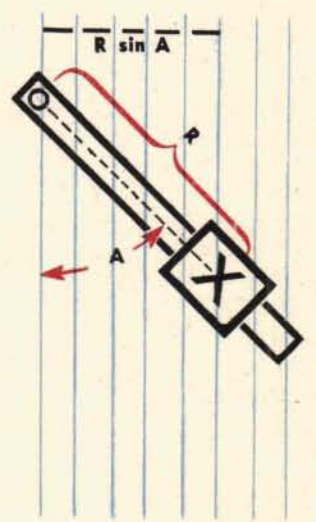
$$\text{Sine of an angle} = \frac{\text{opposite side}}{\text{hypotenuse}}$$

For example, in this triangle, $\sin A = \frac{D}{R}$, or $D = R \sin A$



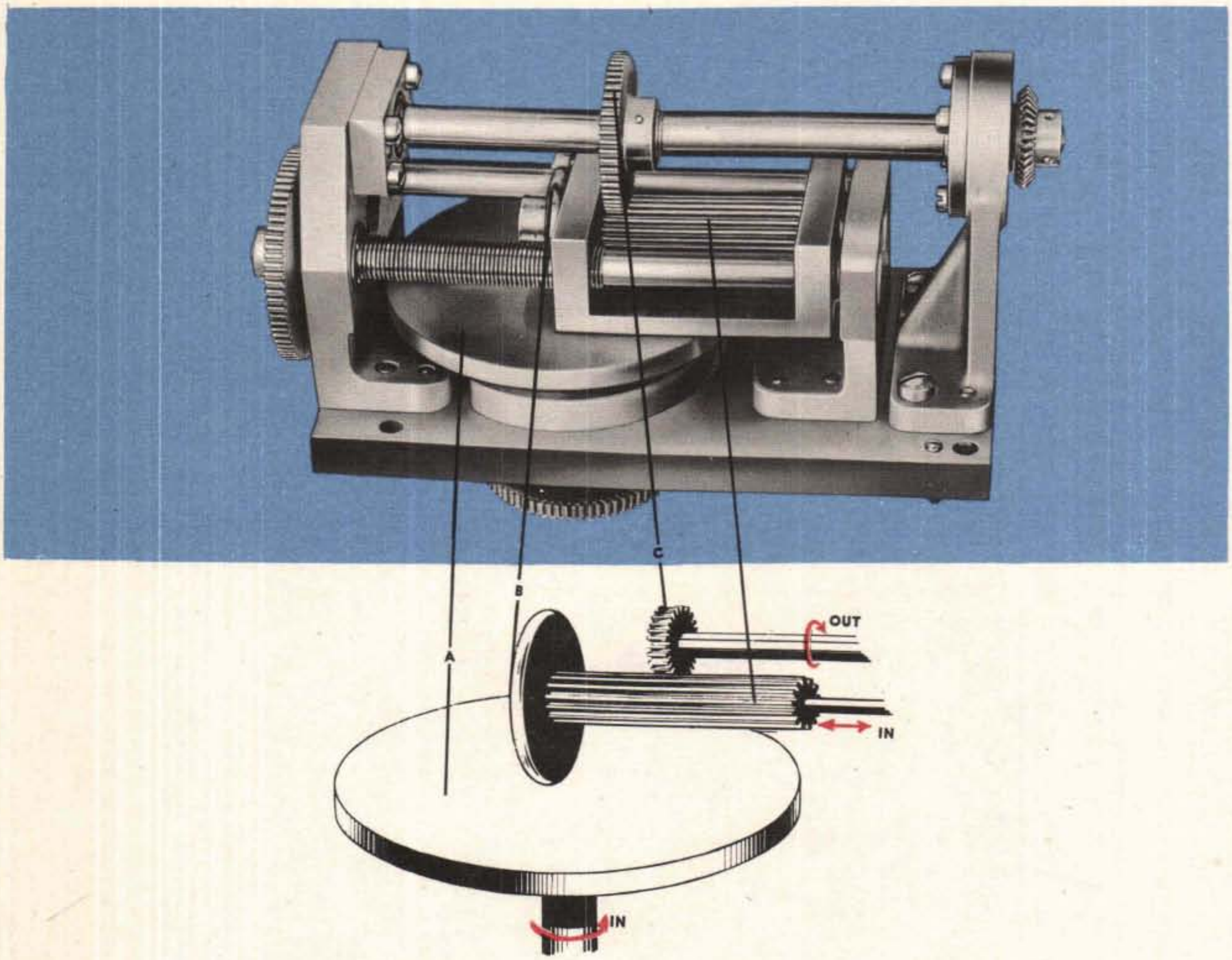
For different values of angle A, the length D will change and the point X will be various distances above the base of the triangle. Hence a resolver may be constructed to give values of $R \sin A$.





In this resolver a nut travels on a threaded rod or arm. The angular position of the arm is determined by the angle A. The value of R is the distance from the pivot to the X mark on the nut and is determined by the rotation of the rod about its own axis. The nut is prevented from rotating, and as the rod rotates, the nut travels axially along it. $R \sin A$ is read from the intersection of the X mark with the vertical $R \sin A$ graduations. $R \sin A$ may be varied either by changing angle A, changing the position of the nut on the arm, or both.

INTEGRATORS



This integrator is used for multiplying two values, each of which may vary continually. The values are represented by inputs and the integrator gives the product of these inputs at each instant.

If the integrator is connected to a counter, these instantaneous products will be set into the counter as they are obtained. That is, the quantity shown on the counter at any instant will represent the sum of all the instantaneous products obtained up to the moment a reading is taken.

The integrator, therefore, not only multiplies, but sums up the instantaneous products of the two inputs as these inputs vary.

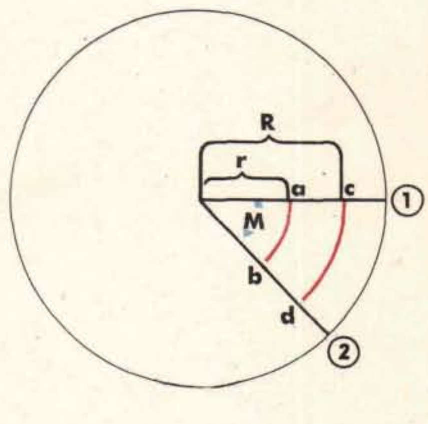
When used in conjunction with a motor and a follow-up head, this unit may also be used for division. See page 370.

One of the inputs to the integrator rotates the large disk *A*, and the other input consists of locating the follower roller *B* at various radii on the disk. As the disk revolves, it causes the roller to rotate and transmit the motion to the output pinion C.

The amount of rotation of *B* depends upon its distance from the center of disk *A*, and upon the rotation of *A*. If disk *A* is rotated and *B* is at the center of *A*, there will be no rotation of *B*. But if *B* is moved away from the center of *A*, *B* will start to rotate, and its speed of rotation will increase the nearer it is brought to the edge of the disk.

In other words, for a given speed of the disk, the rotation of *B* is zero when the point of contact is at the center of the disk, and rotation of *B* is maximum when the point of contact is at the edge of the disk.

Here motion of the disk from position 1 to position 2 through the angle *M* is shown. If a point *a* is at the radius *r*, this point moves through the arc during the rotation.



1 arc $ab = M \times r$

where the angle *M* is expressed in radians. When another point c is at a radius *R*, its movement equals the arc *cd*.

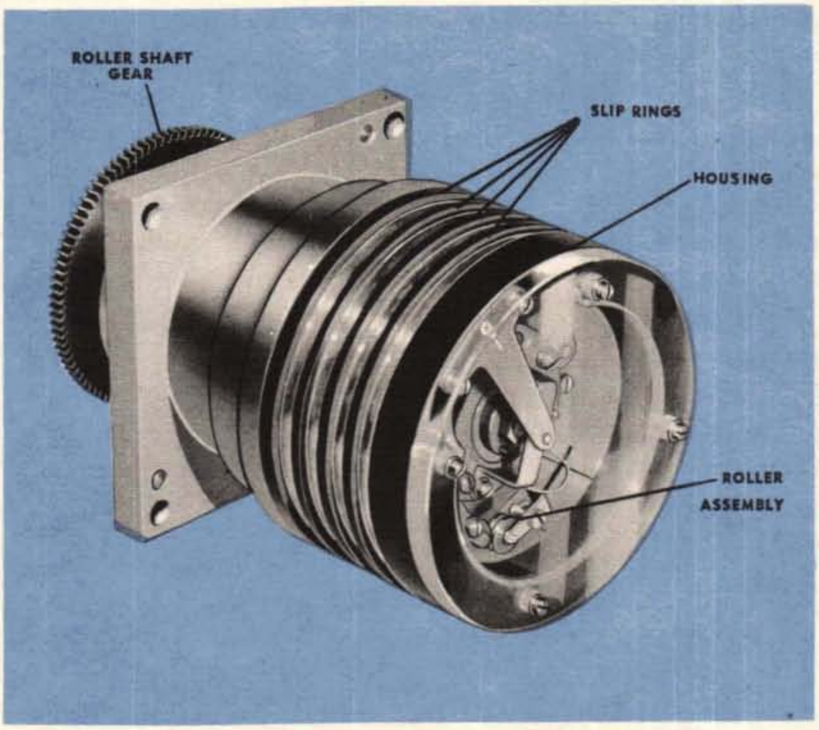
2 arc $cd = M \times R$

where the angle *M* is again expressed in radians. Then from equations 1 and 2

3 $\dfrac{\text{arc } ab}{\text{arc } cd} = \dfrac{Mr}{MR} = \dfrac{r}{R}$

If the follower rolls on the disk without slipping, it rolls an amount equal to the arc *ab* when the point of contact is a distance *r* from the center and the rotation of the follower equals the amount of $M \times r$. Also it can be seen from Equation 3 that the amount of movement is directly proportional to the radius. When the radius is zero or when *M* is zero, $M \times r = 0$ and the follower does not move. Since the rotation of the follower equals $M \times r$ the mechanism creates the sum of instantaneous products of *M* and *r* as either or both of these quantities vary. When neither *M* nor *r* vary, the integrator operates as a simple gear ratio and the result is pure multiplication.

FOLLOW-UP HEADS

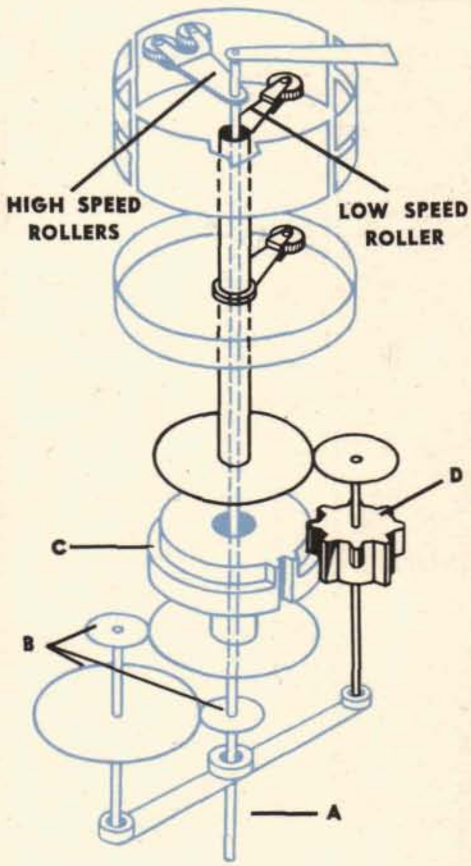


The follow-up head shown here has two uses. First, it may be used in a mechanical circuit to control electrically the direction and amount of rotation of a follow-up motor to increase the driving power in the system. The follow-up head may also be used for matching mathematical quantities.

In most applications, the input drive displaces the head of the unit, while the response drive from the follow-up motor enters directly (or indirectly through an element in the mechanical circuit) and matches the input drive by displacing the rollers. However, it can be used with the response drive connected to the head and the input connected to the rollers.

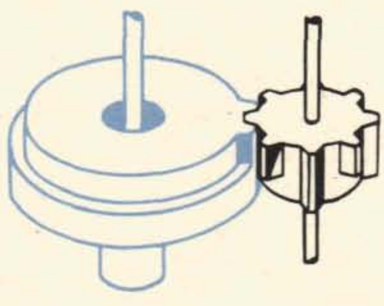
The parts and how they work together

Here is the mechanism shown diagrammatically. The main driving shaft *A* is directly connected to the high-speed rollers and also to a reduction gear train *B*, which, through a transfer gear assembly, drives a low-speed roller.

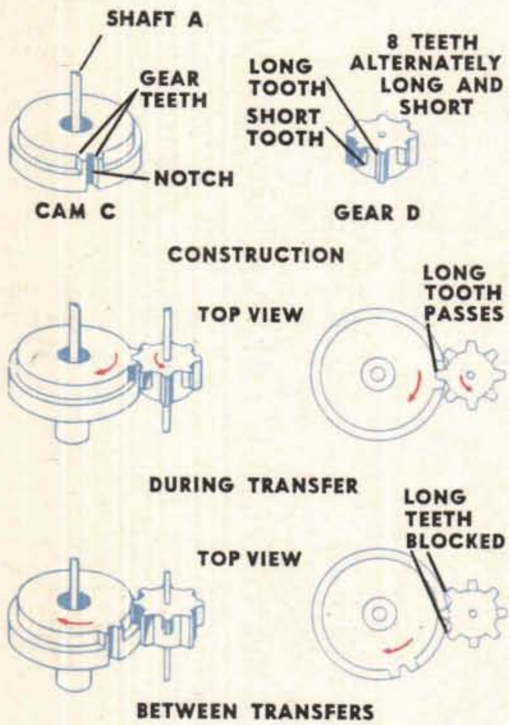


The gears *B* provide a 9 to 1 reduction in speed which is delivered to the locking cam *C* and the intermittent gear *D*. The upper half of cam *C* is a portion of a gear made with a pitch diameter for 20 teeth, only two of which are left on the periphery, as shown. Therefore, the two teeth require 2/20 or 0.1 revolution for their action period, being inactive then for the remaining 0.9 of each revolution.

Since *C* only moves 1/9 of the speed of *A*, the shaft *A* must turn 9×0.1 or 0.9 revolution in order to make the two teeth on cam C go through a complete transfer. When the transfer mechanism is in the position shown in the figure below, the intermittent gear is halfway through a transfer motion, and it will require only 0.45 revolution of *A* in either direction to complete the movement. After a transfer has been completed, shaft *A* must turn through 9×0.9 or 8.1 revolutions before a transfer begins again. The low-speed roller is geared so that it moves 45° during a complete transfer. It is prevented from moving during 8.1 revolutions of shaft *A* by the locking cam *C*. During the transfer motion a notch in the cam permits passage of one long tooth on the intermittent gear, but further motion of the intermittent gear, which drives the low-speed roller, is prevented by the lack of notches and the absence of driving gear teeth on the top half of cam *C*.



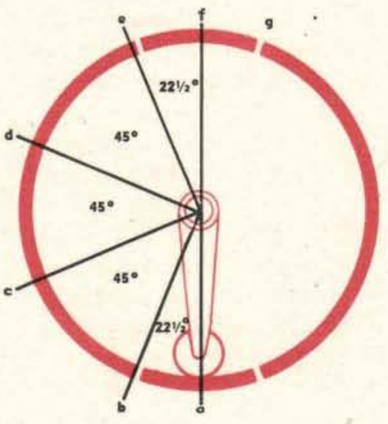
The INTERMITTENT GEARING



In this illustration the constructional details of the cam *C* and gear *D*, as well as the locking action between transfers, are shown. The single notch in the lower portion of cam *C* is a continuation of the "valley" between the two driving teeth on the upper portion of the cam. The diameter of the lower part of the cam is the same as the major diameter of the gear which forms the upper portion of the cam. The diameter of the greater part of the upper portion is the same as the minor (root) diameter of the two gear teeth cut on it. When the cam and gear are in the transfer position, the two teeth on the upper part of cam *C* engage and move one of the long teeth on the gear *D*, while the notch in the lower part of the cam allows this tooth free movement to complete a transfer, producing a one-quarter turn of the intermittent gear. As the tooth leaves the notch, another long tooth approaches and makes contact with the lower peripheral surface of the cam to be in position to enter the notch during its next time around. During this waiting period, therefore, two long teeth on the intermittent gear are in contact with the notchless surface of the cam, thus locking the gear in this position until the notch in the cam again arrives at one of these two teeth. During this time also, one of the short teeth of the gear *D* rests in the clearance space provided by the missing teeth on the upper portion of the cam, and awaits contact by one of the two teeth on the cam. The four short teeth, alternately spaced between the long teeth of the gear *D*, are merely for the purpose of starting motion of the intermittent gear when the cam notch has approached the position required for passage of one of the long teeth.

This type of follow-up head has a "storage" capacity of 35.55 revolutions of shaft *A*, obtained as follows: Since the low-speed roller only moves the amount provided by half a transfer before coming to a stop due to locking of the cam, it will move $22\frac{1}{2}°$ (starting with the tooth in the notch). During the $22\frac{1}{2}°$ motion, shaft *A* (and the high-speed roller) moves 0.45 revolution. The successive positions of the low-speed roller are shown on the next page.

The high-speed and low-speed rollers



In the "matched position" of the head, which occurs when the response drive has equalled the input drive and the follow-up motor actuated by the head is no longer energized, the low-speed roller is at *a*. If now the response drive remains de-energized while an input is applied to the follow-up head rollers, the following motions of the low-speed roller occur.

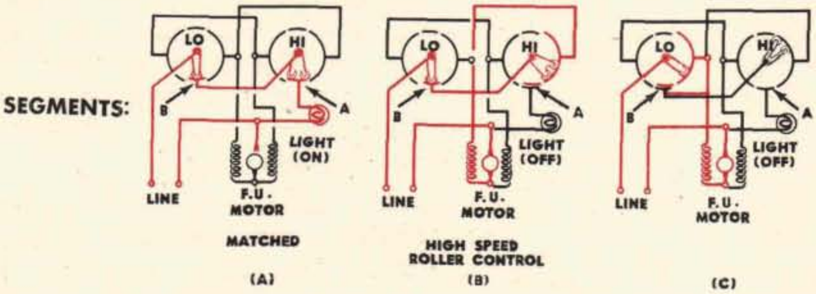
After the first one-half transfer, the point *b* is reached where the roller remains for the following 8.1 revolutions of *A*. Then, during the next 0.9 revolution of *A*, the roller travels to the point *c* where it remains for another 8.1 revolutions of *A*. Traveling to point *d* requires another 0.9 revolution of *A*, and after remaining there for 8.1 revolutions of *A*, another 0.9 revolution carries the roller to *e*. Shaft *A* can rotate another 8.1 revolutions before it starts to move the roller again, but any further movement of the roller will bring it to a dead segment at point *f*. The second half of the transfer would carry the roller to the contact at *g* which would connect the opposite field winding of the follow-up motor and cause the motor to turn in the wrong direction for synchronizing if the response drive were re-energized. Therefore, the total of all motion of *A* up to the beginning of the transfer of the roller from *e* to *f* adds up to 35.55 revolutions. This is the amount of displacement of shaft *A* of which the follow-up head is able to keep account. In other words, if there is any displacement of the shaft *A* up to a maximum of 35.55 turns, the follow-up will synchronize in the proper direction to match the input quantity.

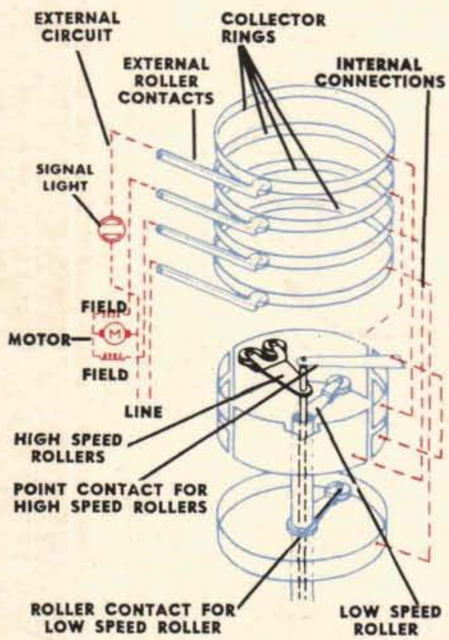
This storage capacity is obtained in the same amount (35.55 turns) in either direction from the matched position. The addition of another transfer gear and intermittent gear could be made to multiply the storage capacity of the head by approximately ten to give a capacity of 359.55 turns in either direction.

The circuits in high-speed and low-speed control

Movement of the high-speed rollers normally controls the follow-up motor without causing the low-speed roller to leave its matched position segment. Follow-up is continuous as long as the circuit is energized. However, if the circuit is open for any reason, the follow-up motor will not run, and under such conditions the ability of the follow-up head to store up a number of revolutions is of value. When the circuit is again closed, the motor can start in the proper direction and catch up to the driving shaft.

Three conditions may exist in the follow-up action.





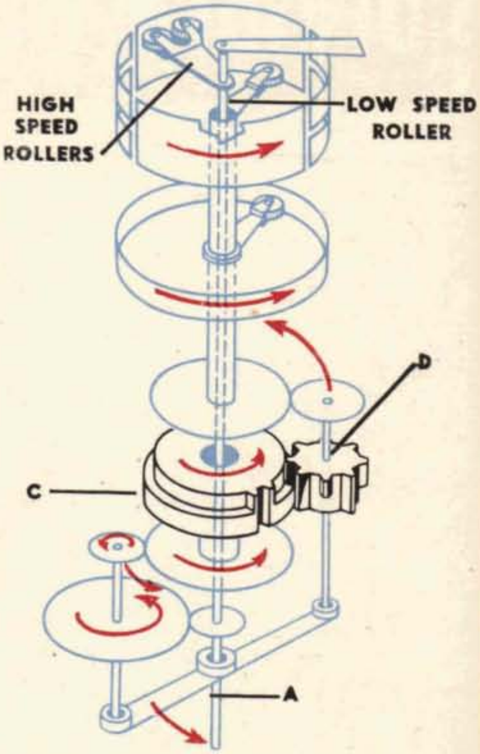
In the circuit diagrams, the red-colored leads indicate energized circuits. In sketch *A* the follow-up head is matched; the circuit to the follow-up motor is incomplete to both fields, and the indicating lamp is lighted. In sketch *B* the high-speed rollers have been displaced a few degrees, but not enough to cause transfer of the low-speed roller to controlling position. Now the motor is energized by completing the circuit through the proper field to cause it to run in the direction to restore the original relationship between the roller and segment *A*. Until this matching occurs the motor runs and the indicator light is off. In sketch *C* the head has stored up a few turns and the low-speed roller is in control of the motor. The high-speed roller is no longer energized and the indicating lamp is off. As the motor runs to restore the original matched relationship, the high-speed roller (or the head around the rollers) moves until a transfer places the low-speed roller on segment *B*, thus allowing the high-speed roller to assume control and bring the follow-up head into synchronism.

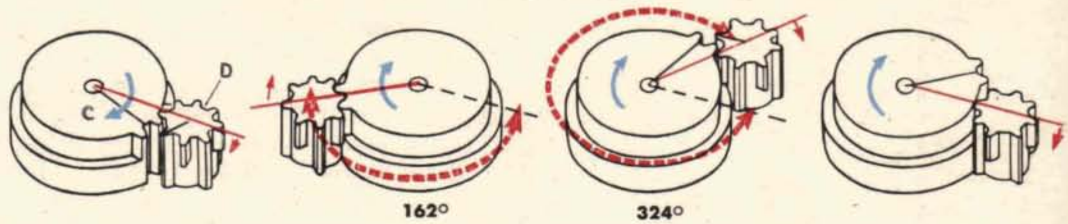
How the matched position is restored

If an input to the roller assembly has caused the head to store up a few turns, the action in restoring the matched condition is as follows: The shaft *A* and the high-speed rollers are assumed to be stationary at any position, and the follow-up motor is turning the head in the proper direction to "catch up" to the matched position. The head carries with it the gears and bearings of the transfer mechanism; therefore the low-speed roller and intermittent gear *D* will be carried along until the gear reaches the two teeth on the cam *C* and goes through a transfer. From previous explanations, it was seen that if the follow-up head were held stationary at this point and the shaft *A* turned 0.9 revolution, a transfer would take place, moving the low-speed roller 45°.

Similarly, at this point, if input shaft *A* is stationary and the head is turned 0.9 revolution, the low-speed roller will transfer 45° *with respect to its former position in the head.* However, this transfer takes place while the head and roller are still in motion, after which the low-speed roller and head travel together but in different relative positions until the next transfer. The roller loses ⅛ revolution in the head at each transfer. Since the 9 to 1 gear reduction mechanism is also traveling with the head, the cam *C* is traveling in the same direction, at a speed of 8/9 that of the intermittent gear and its supports; therefore, it will take nine revolutions of the head in order for the gear *D* to catch up to the transfer teeth of cam *C* and complete another transfer. (See illustration below.)

This sequence of transfers continues until a final transfer brings the low-speed roller onto the segment which transfers control to the high-speed rollers. The high-speed rollers then bring the follow-up head to its matched position and continue to keep it matched.

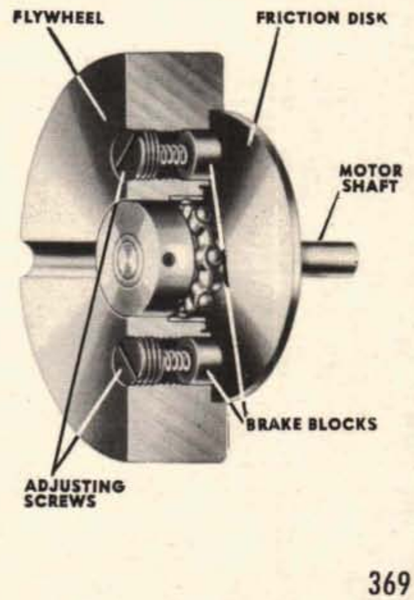




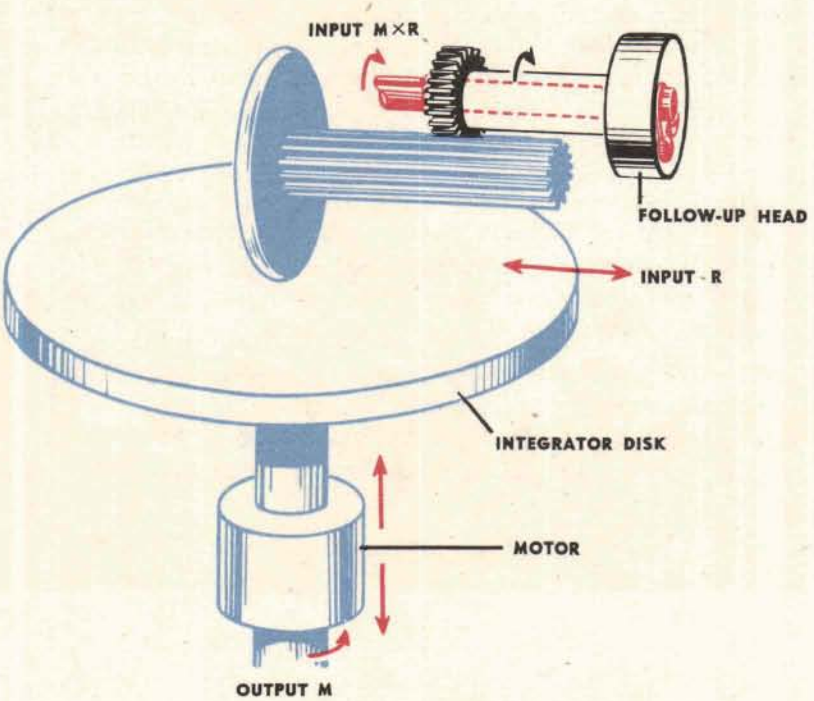
INTERMITTENT GEAR D GOING THROUGH TRANSFER MOTION

MECHANICAL DAMPERS

Mechanical dampers (inertia-type oscillation-damping devices) are employed with the follow-up motors to prevent the system from "hunting" as the matched position is reached. The damper shown consists of a flywheel carrying two brake-blocks which contact a disk pinned to the motor shaft. The only connection between the motor and the flywheel is by friction between the brake-blocks and the disk. As the motor tends to accelerate or decelerate, part of the inertia of the flywheel will attempt to prevent speed changes. The amount of flywheel effect may be varied by changing the amount of friction. This is accomplished by turning the adjusting screws which change the compression in the brake-block springs.



DIVIDER WITH FOLLOW-UP HEAD

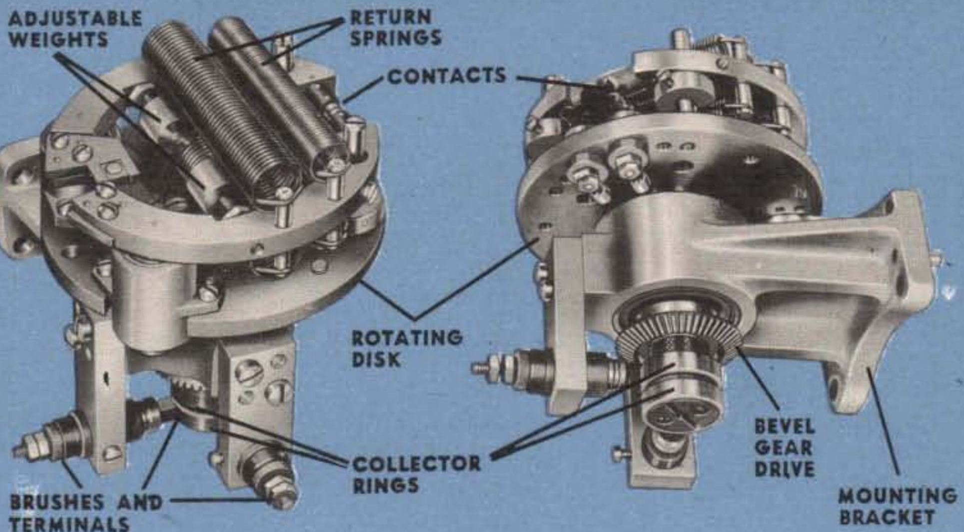


The follow-up head is used to give power to signals from other mechanisms. The follow-up motor will drive a load the same number of revolutions as the follow-up head is driven by a weak mechanism, which is itself unable to drive the load.

The follow-up head is also used for matching mathematical quantities in, for example, the integrator of the divider unit when performing division.

The divider unit is made up of three parts: an integrator, a follow-up head, and a follow-up motor. The integrator roller is positioned by one input (quantity R) and the other input (quantity $M \times R$) operates the follow-up head rollers. The motor which drives the integrator disk is controlled by the follow-up head in such a way that the disk rotates and causes the roller to turn the correct amount $M \times R$ to make the body of the follow-up head continuously match the follow-up head rollers. This disk rotation must be the quantity M, which then may be taken from the motor shaft for other uses. The follow-up head makes it possible, therefore, to match the given quantities R and $M \times R$ to obtain the desired quantity M as an output.

TIME MOTOR GOVERNOR



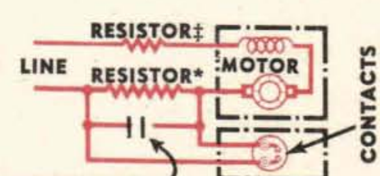
The cast aluminum mounting bracket which supports the governor assembly is secured so that the bevel gear engages a similar bevel gear on the output mechanism of the Time Motor. The bevel gear drives the rotating disk upon which are mounted two ball-bearing pivoted arms, each of which carries a contact and an adjustable weight. Collector rings and brushes serve to connect the contacts to the external circuit.

Four coil springs act to hold the contacts together. These springs are sufficiently strong to keep the two arms positioned with the contacts closed, so long as the motor does not exceed 1200 R.P.M.

When the motor runs at over 1200 R.P.M., the speed at which the governor assembly is rotated results in sufficient centrifugal force to overcome the action of the springs, causing both arms to be thrown outward. When this occurs, the contacts are separated. The current supply to the Time Motor is cut off, and the motor slows down.

The reduction in speed causes the centrifugal force to diminish and allows the springs to close the contacts again. This action continues several times per second and holds the motor to an average of 1200 R.P.M.

The fundamental circuit for this type of control is shown here.



SECTION 7
LINKAGE MECHANISMS

Other sections of this OP describe basic mechanisms consisting of gears, cams, and other rotating parts. Computations made by these basic units in the solution of a fire control problem are also described.

These same computations can be made with linkage mechanisms. Linkages are designed to accomplish the work of gearing units but with fewer moving parts. Linkage mechanisms contain links, levers, or cranks as essential computing elements. Like gearing units, linkage mechanisms may also include gears or slides. However, these gears or slides are always combined with purely linkage elements to form the complete linkage mechanism. In linkage mechanisms, values are usually represented by linear movements of links rather than by angular movements of gears.

This section describes the basic linkage mechanisms that are used for solving fire control problems. Adjustments that apply particularly to linkage mechanisms are illustrated.

This section also describes mechanisms that do not compute, but serve some other purpose such as limiting the movement of a linkage.

Finally, this section includes a description of a simplified network of linkage mechanisms, illustrating how they work together to solve a fire control problem.

Accuracy of Linkage Mechanisms

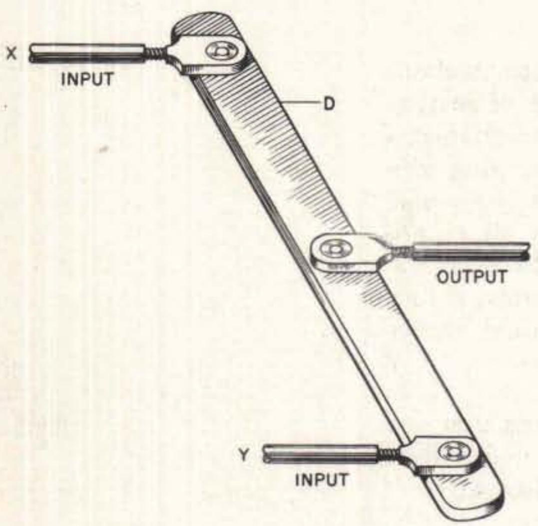
In illustrating the operation of linkage mechanisms, movements of links have been exaggerated for the sake of clearness. This creates the illusion that these linkages are inaccurate. Actually, the links are so long in proportion to their movements that any error introduced in their operation is negligible.

Further information concerning accuracy can be found under the heading DISTORTION, included in the description of each mechanism.

DIFFERENTIALS

LINKAGE TYPE DIFFERENTIALS

The linkage type differential has the same function as the conventional gear type differential; that is, the addition or subtraction of two quantities. In this differential, however, the inputs and outputs are represented by linear movements of links rather than by rotation of gears.

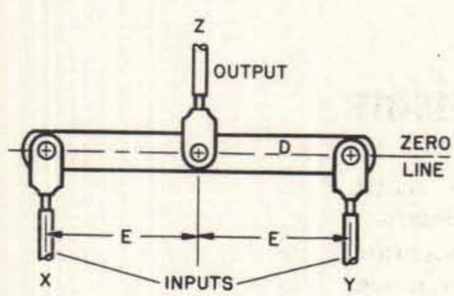


LINKAGE TYPE DIFFERENTIAL

The differential consists of a bar D to which three links, $X, Y, Z,$ are connected by means of pivot pins. For the present, it is assumed that the two end links are the inputs and the middle link is the output. Later it will be shown that either end link can be made an output and that the inputs can be applied to the other two links.

If the output link is pivoted on bar D midway between the two input links, the value of the output is proportional to the sum or difference of the inputs. Any other location of the output link will result in a sum or difference of the form $(x+Ky)$ or $(x-Ky)$. The value of the constant, K, depends upon the location of the output link relative to the two input links.

Adding: x + y

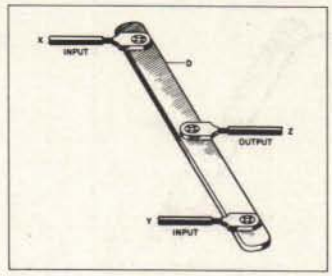


ZERO POSITION

The addition of two quantities is accomplished by moving both input links in the same direction, provided the output link is located between the input links.

Assume a differential with input links X and Y located at the ends of a bar D and an output link Z located at the center of the bar. With inputs X and Y at zero, bar D will be positioned along the zero line.

If input X is moved upward a distance x, while input Y remains stationary, the output moves upward a distance a, an amount depending upon the relative distance between pivots on bar D. The distances x and a form the sides of two similar triangles. (For a description of similar triangles, see page 28.) In two similar triangles, the ratio between any two sides of one triangle is equal to the ratio between the corresponding two sides of the other triangle. Therefore:



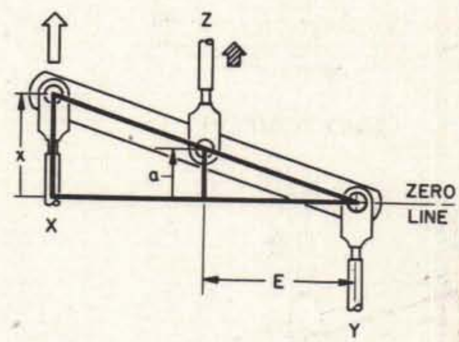
$$\frac{a}{E}=\frac{x}{2E}$$

where E is the distance from output Z to inputs X and Y. Multiplying both sides by E:

$$\frac{Ea}{E}=\frac{Ex}{2E}$$

Then:

$$a=\frac{x}{2}$$



x INTRODUCED

If input X remains fixed at its new position, and Y is moved upward a distance y, the output moves upward a distance b. Making use of similar triangles again:

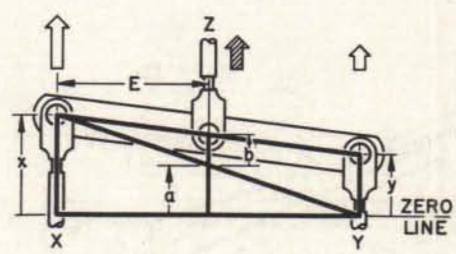
$$\frac{b}{E}=\frac{y}{2E}$$

Then:

$$b=\frac{y}{2}$$

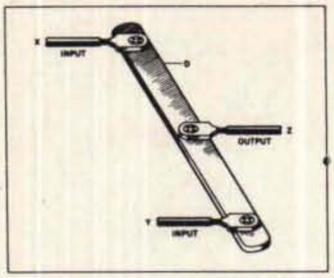
The total movement of the output link Z is $(a+b)$, or z.

$$z=a+b=\frac{x}{2}+\frac{y}{2}=\frac{x+y}{2}$$

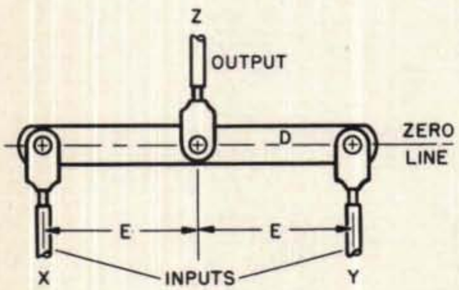


y ADDED TO x

Although the actual movement of the output link equals *one-half* the sum of the input movements, the output movement nevertheless *represents* their sum, but to a different scale; that is, to a different value per linear inch of link movement. If necessary, the scale of the output movement can be converted to the scale of the input movements by means of a simple linkage multiplier, described later.



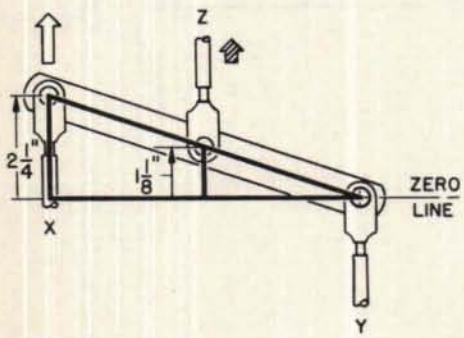
Subtracting: x – y



ZERO POSITION

The same differential may be used for subtraction by moving the input links in opposite directions. In this case, the total output equals one-half the difference of the inputs.

If X is moved upward $2\frac{1}{4}$ inches, while Y remains fixed, Z moves upward $1\frac{1}{8}$ inches.



x INTRODUCED

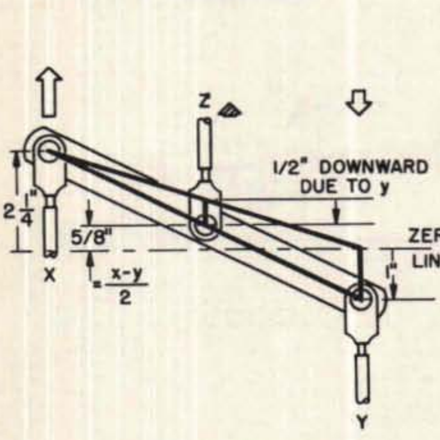
If X is fixed at its new position and Y is moved downward one inch, link Z moves downward $\frac{1}{2}$ inch.

The total movement of Z from its initial position at the zero line is:

$$z = \frac{2\frac{1}{4}'' - 1''}{2} = \frac{5''}{8} \text{ upward}$$

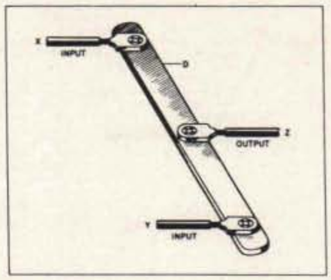
or

$$z = \frac{x}{2} - \frac{y}{2} = \frac{x-y}{2}$$



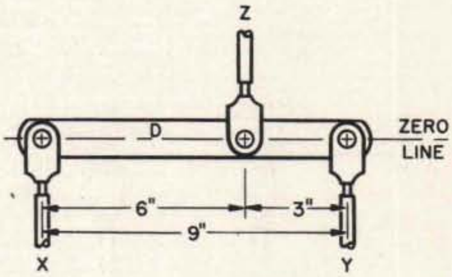
y SUBTRACTED FROM x

Therefore, the total movement of the output link is equal to one-half the difference between the movements of the two inputs. This net movement, nevertheless, represents the difference between the two quantities, but to another scale.



Adding: x + Ky

By locating the pivot point of output link Z off-center on bar D, a sum of the form $(x + Ky)$ may be obtained.

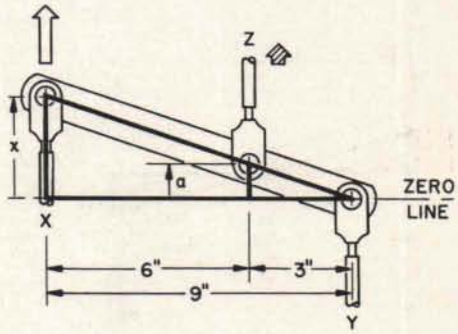


ZERO POSITION

Assume bar D to be nine inches long and link Z to be connected three inches from link Y. If X is moved upward, with Y fixed, Z will move a distance a.

Making use of similar triangles:

$$\frac{a}{3} = \frac{x}{9}, \quad \text{or} \quad a = \frac{x}{3}$$



x INTRODUCED

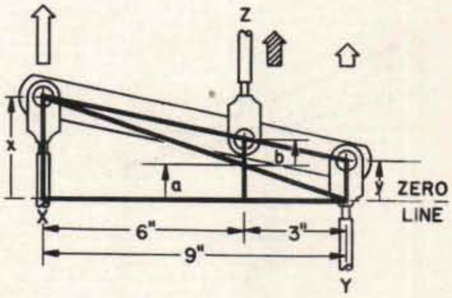
If X is fixed at its new position and input Y is moved upward a distance y, output Z moves a distance b. Then:

$$\frac{b}{6} = \frac{y}{9}, \quad \text{or} \quad b = \frac{2}{3}y$$

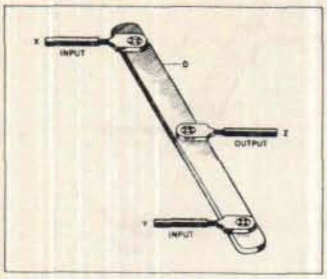
The total movement of Z is $(a + b)$. Therefore:

$$z = a + b = \frac{x}{3} + \frac{2y}{3} = \frac{x + 2y}{3}$$

In this case, the value of the constant K is two, and the total movement of the output link is equal to one-third the sum of x and $2y$.



Ky ADDED TO *x*



Other Arrangements

Any two links of the differential can be used as inputs, and the remaining one can be used as the output, depending upon which arrangement proves most convenient mechanically. However, if one of the end links is used as the output, the addition of two quantities is accomplished by moving the input links in opposite directions. Since, in this arrangement, the output link is not equidistant from both input links, sums of the form $(x+Ky)$ are obtained.

Assume that the output link Z is located at the left end of bar D, that input X is at the right end, and that input Y is at the center of the bar.

If input X is moved downward a distance x while input Y remains fixed, output Z will move upward a distance a. From the similar triangles formed:

$$\frac{x}{4}=\frac{a}{4} \quad \text{or} \quad a=x$$

If X is fixed at its new position and input Y is moved upward a distance y, output Z moves upward a distance b. Therefore:

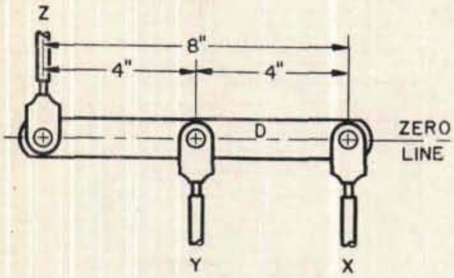
$$\frac{y}{4}=\frac{b}{8} \quad \text{or} \quad b=2y$$

The total movement of the output link Z is $(a+b)$, or z.

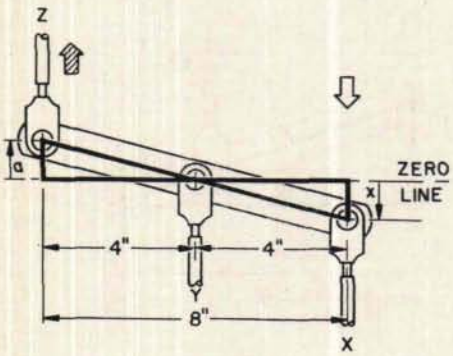
$$z=a+b=x+2y$$

The value of the constant K is two.

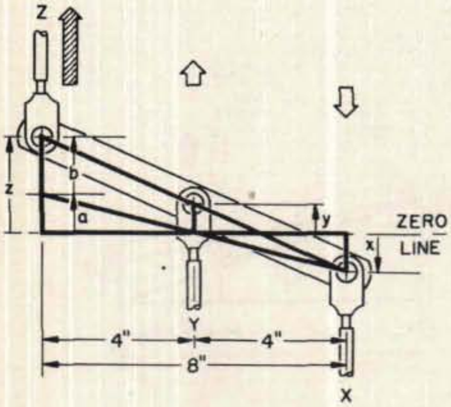
Subtraction in this arrangement is accomplished by moving the two input links in the same direction. Differences of the form $(x-Ky)$ are obtained.



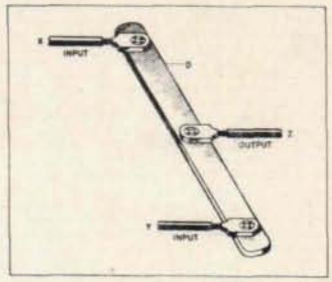
ANOTHER ARRANGEMENT



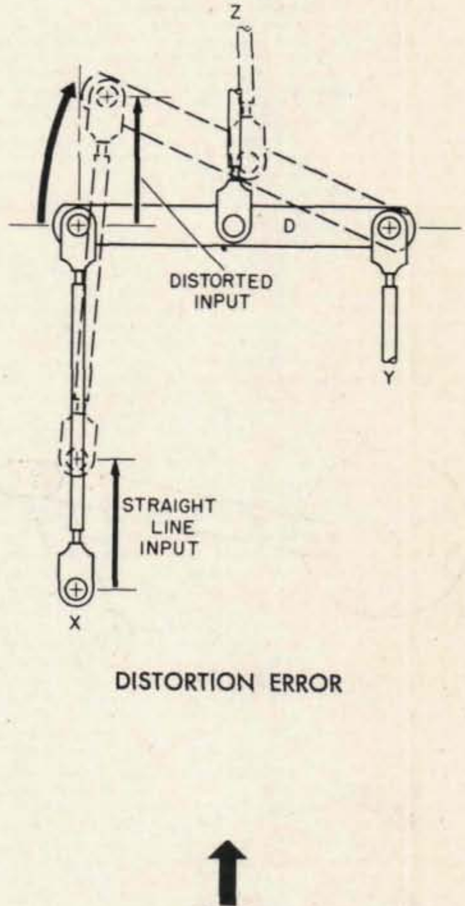
x INTRODUCED



Ky ADDED TO x



Distortion of Output

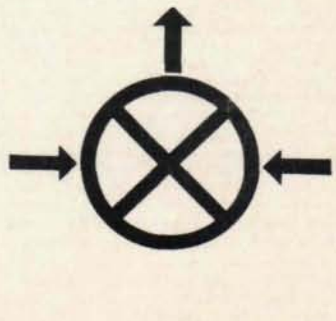


DISTORTION ERROR

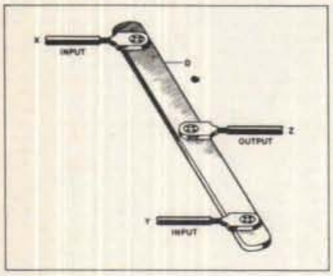
Since the length of bar *D* is fixed, the inputs will not actually be applied in a straight line even though one end of each input link moves in a straight line. This distortion causes errors to be introduced in the output.

Suppose input link *X* is moved upward while input *Y* remains fixed. The upper end of link *X*, which is connected to bar *D*, moves in an arc although the lower end moves in a straight line. The input to bar *D* is therefore slightly less than the actual input supplied to link *X*. This error, however, may be kept insignificant by limiting the angular motion of bar *D*.

Schematic Symbol



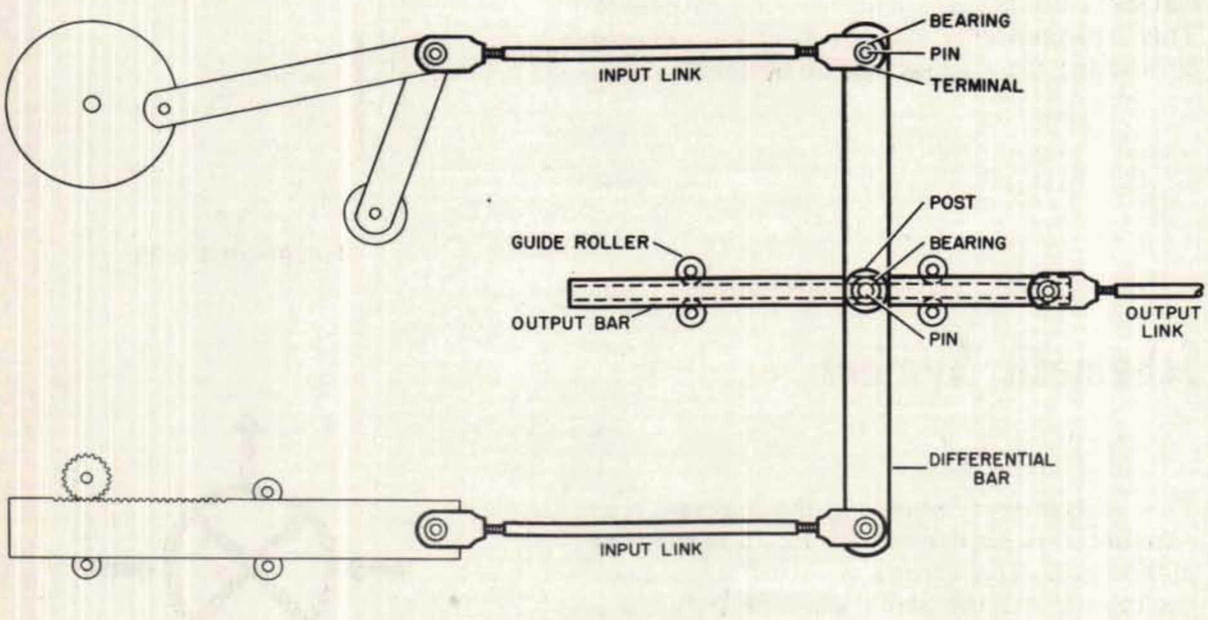
The schematic symbol for the linkage type differential is similar to that for the gear type differential. The arrows pointing inward are the inputs, and the arrow pointing outward is the output.



Construction of a Typical Unit

Here is a typical linkage type differential. Each link assembly consists of a rod and two terminals. The ends of the rod are screwed into these terminals. The terminals hold the pivot bearings. One terminal is ball bearing mounted on a pivot pin fixed to the top of the differential bar or output bar. The other terminal is ball bearing mounted on another linkage mechanism.

The differential bar is ball bearing mounted on a pivot pin fixed to the top of an output bar. The output bar, in turn, is held by guide rollers which allow it to move in a straight line parallel to the input links. Its straight line movement is imparted to the output link through a pivot pin which supports a terminal of the output link.



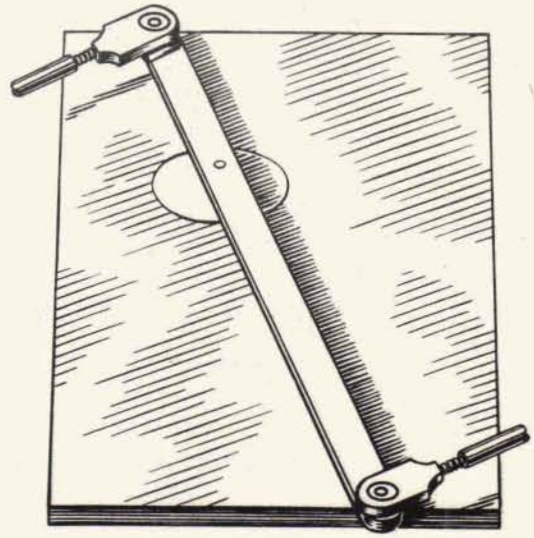
TYPICAL DIFFERENTIAL

MULTIPLIERS

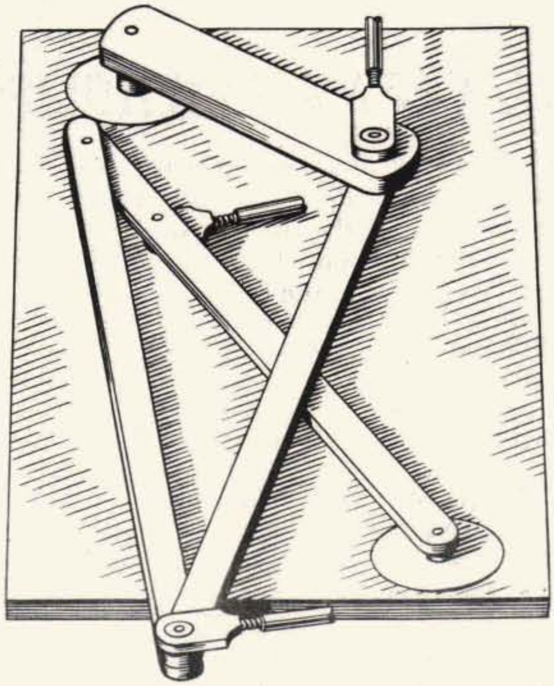
LINKAGE TYPE MULTIPLIERS

There are two general types of linkage multiplier. One type multiplies a variable quantity by a constant. Its function is similar to that of a gear ratio for changing the value per revolution of a shaft line in a gearing unit. The lever multiplier and the bell crank multiplier are of this type.

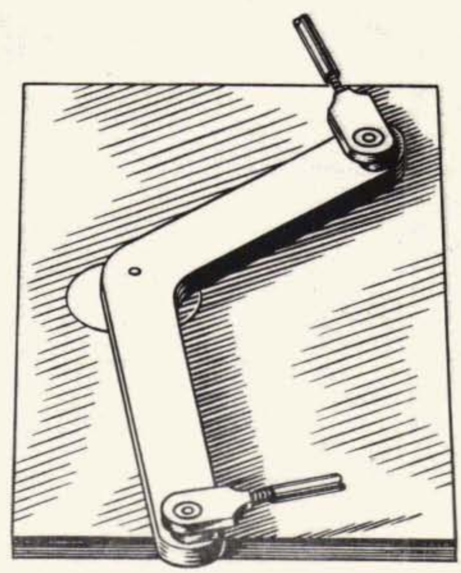
The other general type of linkage multiplier is used to multiply two variable quantities. The output of this multiplier is directly proportional to the product of two inputs. This multiplier is known as the *XY* linkage multiplier.



LEVER TYPE MULTIPLIER

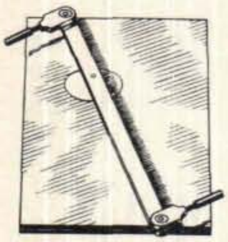


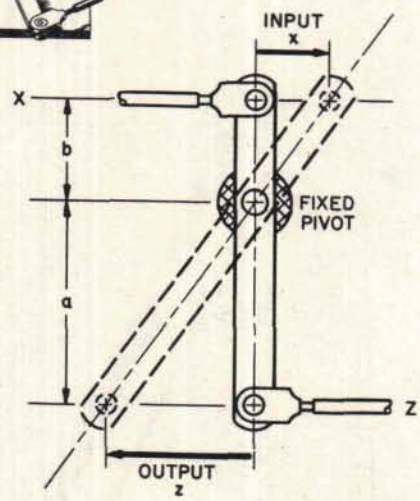
XY TYPE MULTIPLIER



BELL CRANK TYPE MULTIPLIER

THE LEVER MULTIPLIER





LEVER MULTIPLIER

The lever multiplier is simply a straight bar which has a fixed pivot at some point in its length. Connected to the bar are two links; an input link and an output link. The direction of motion of the input link is parallel to the direction of motion of the output link.

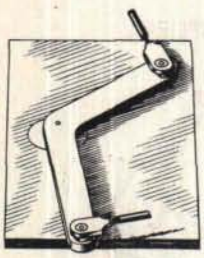
The output of this multiplier is equal to its input multiplied by a constant. The value of the constant depends upon the location of the fixed pivot on the bar relative to the pivots for the input and output links.

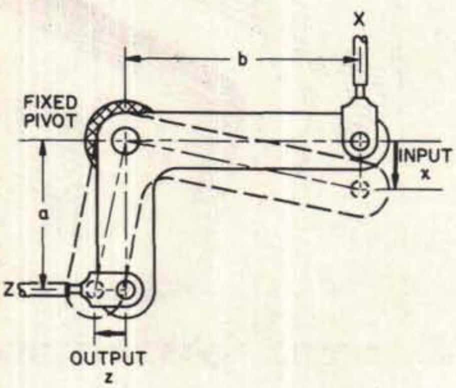
If the input link is moved a distance x, the output link will move a distance z. From the two similar triangles formed:

$$\frac{z}{a}=\frac{x}{b} \quad \text{or} \quad z=\frac{a}{b}x$$

Therefore the output is equal to the input multiplied by a constant, the value of the constant being a/b. The fixed pivot is located along the bar at a position that establishes the required ratio of a to b.

THE BELL CRANK MULTIPLIER





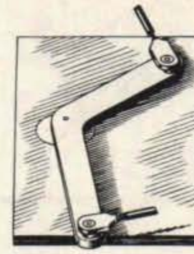
BELL CRANK MULTIPLIER

The bell crank multiplier is a bar whose two arms form an angle and whose fixed pivot is at the vertex of the angle. An input link is connected to one arm of the bar and an output link is connected to the other.

As in the case of the lever multiplier, the output is equal to the input multiplied by the ratio a/b, where a is the length of the output arm and b is the length of the input arm.

Unlike the lever multiplier, however, the direction of motion of the output is not parallel to the direction of motion of the input. The input and output motions are directed at right angles to the arms to which the links are connected. The angle between the two motions therefore depends upon the angle between the two arms.

Distortion

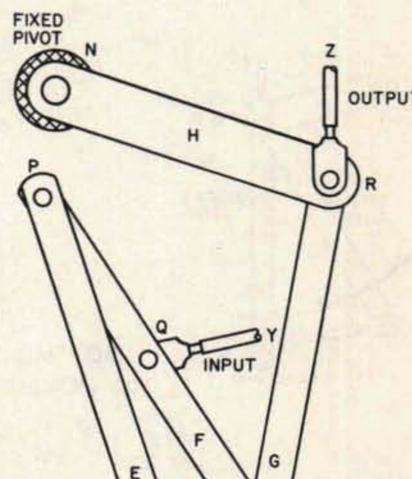


Both the lever multiplier and the bell crank multiplier are subject to distortions of the same sort as the linkage differential. However, errors in the output can be kept small by limiting the motion of the inputs.

Schematic Symbol

The schematic symbol for the lever and the bell crank multipliers, which are of the type having one input, is a multiplication sign enclosed in a circle, with the input arrow pointing toward the center of the circle.

THE XY LINKAGE MULTIPLIER



Ky ADDED TO x

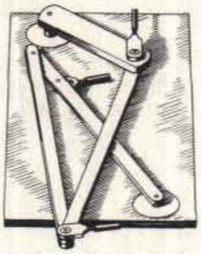
The *XY* linkage multiplier consists fundamentally of three links *E, F,* and *G,* all of equal length. A fourth link, *H,* merely guides link *G* and output link *Z.*

Input link *X* is connected to links *E* and *G* through pivot *O.* Input link *Y* is connected to link *F* through pivot *Q.* Output link *Z* is connected to links *G* and *H* through pivot *R.* Fixed pivots *M* and *N* are centers of rotation for links *F* and *H,* respectively. Pivot *P* joins links *E* and *F.*

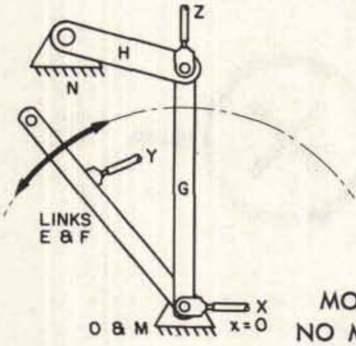
How It Multiplies

The output of the *XY* multiplier is proportional to the product of the two inputs.

It will be recalled that the output of a bell crank multiplier is equal to the product of the input and the fixed ratio a/b, where a is the length of the output arm and b is the length of the input arm. If the ratio a/b could be changed, the value of the output relative to the input would change proportionally.



In the XY linkage multiplier the value of the ratio a/b can be varied by an input. Thus the output is made proportional to the product of the two inputs.

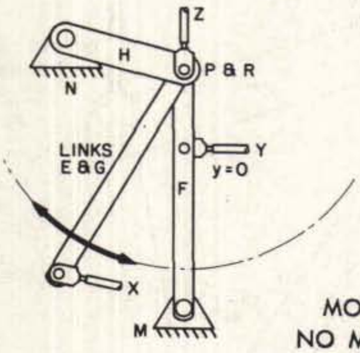


MOVEMENT OF Y
NO MOVEMENT OF Z

Determining the zero position

The zero position of the multiplier is important as a starting point from which to gain information about the operation of the multiplier. It is therefore desirable to establish the zero position before consideration is given to the multiplying action.

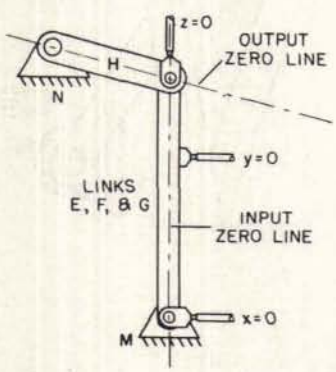
The zero position of the multiplier may be defined as the position of the multiplier linkage when both inputs are at zero. Also, one input may be said to be at zero if the other input can be changed without moving the output. From this fact, the zero position of each input can be determined. Then both inputs can be placed at zero to establish the zero position of the multiplier.



MOVEMENT OF X
NO MOVEMENT OF Z

Assume that input link X is positioned so that links E and F are aligned. As a result, pivot O coincides with fixed pivot M. In this position, movement of input link Y merely rotates links E and F about pivots O and M, respectively. Since pivot O is also the point at which link G is connected to link E, neither links G nor Z are affected by movement of link Y. The zero position of input X is therefore that position which aligns link E with link F.

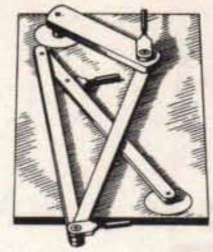
Similarly, assume that input link Y is positioned so that links E and G are aligned. Pivot P coincides with pivot R. Movement of input link X rotates links E and G about pivots P and R but causes no movement of output link Z. The zero position of link Y is therefore that position which aligns link E with link G.



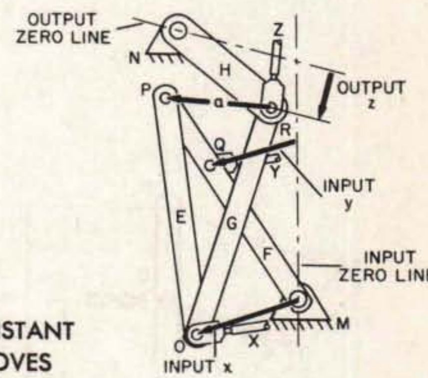
ZERO POSITION

With both input links at their zero positions, all three links E, F, and G, are aligned along a common input zero line; link H defines an output zero line; and the multiplier is at its zero position.

Operation as an equivalent bell crank multiplier

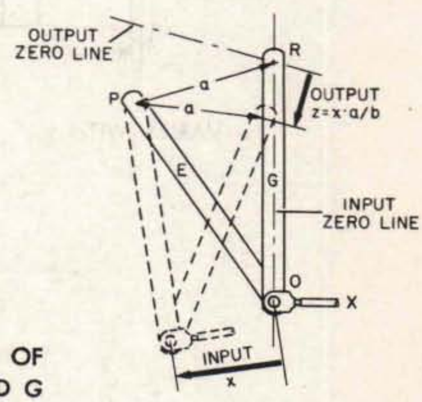


If input link Y is held at a fixed distance y from the input zero line and if movements of link X are small, the XY multiplier operates essentially the same as that of the simpler bell crank multiplier. In this case, its operation is as follows:



Y CONSTANT
X MOVES

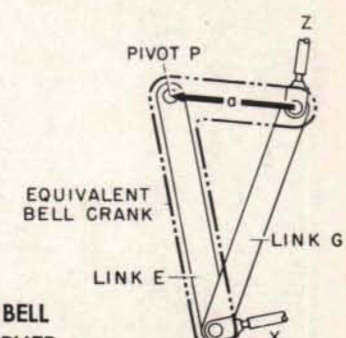
Assume that link X moves through distance x. Pivot P is stationary since link F is restrained by fixed pivot M and the fixed input y. While x changes, link E rotates about pivot P. Link G, connected to the lower end of link E, causes pivot R to move down. Because link H holds pivot R at a constant radius from fixed pivot N, pivot R remains at a nearly constant distance from stationary pivot P. Therefore, a, the distance between pivots P and R, remains *substantially* constant.



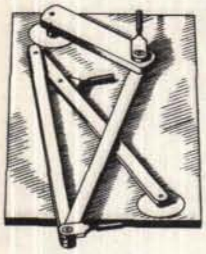
MOVEMENTS OF
LINKS E AND G

With a constant, links E and G form a rigid frame because their lower ends are connected through pivot O and their upper ends are a constant distance, a, apart. This rigid frame operates as an equivalent bell crank, turning about stationary pivot P. Distance a may be considered as one arm of a bell crank multiplier. It is nearly perpendicular to output link Z. The other arm of this multiplier may be considered to be link E, which is nearly perpendicular to input link X. If the length of link E is denoted as b, then, by comparison with the bell crank multiplier described previously, output z equals x multiplied by the ratio a/b, or:

$$z = (a/b)x$$

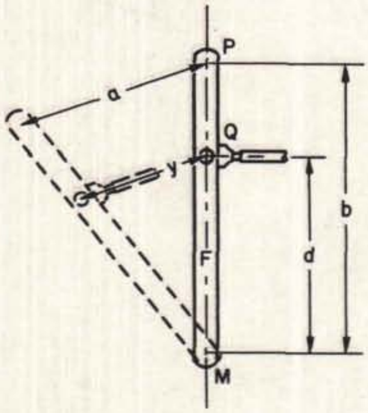


EQUIVALENT BELL
CRANK MULTIPLIER



Multiplication of two variable quantities

The product xy of two variables, x and y, is obtained by making the length of one arm of the bell crank multiplier vary with y. From the previous equation, the output z of the bell crank multiplier equals $(a/b)x$, where x is the input and a and b are the lengths of the crank arms. A second input, y, is introduced by varying a with y. This causes a corresponding change in the ratio (a/b) because b is constant, b being the length of link E. Since (a/b) varies with y and since z equals $(a/b)x$, the output z of the XY multiplier represents the product xy.



a VARIES WITH y

The value of a depends upon two factors. One is the magnitude of y and the other is the distance d of link Y from fixed pivot M. In any multiplier, distance d is constant. This leaves y as the only variable affecting a.

As y increases, a increases in direct proportion because distances y and a are corresponding sides of similar triangles. The exact expression for a may be derived as follows:

Since link F acts as a lever multiplier with its fixed pivot at M, the value of a is equal to the product of the movement y of the input link and the ratio b/d, where b is the length of link F. (Previously the length of link E was designated b. The length of link F, equal to that of link E, may also be designated b.) Therefore:

$$a = \frac{b}{d}y$$

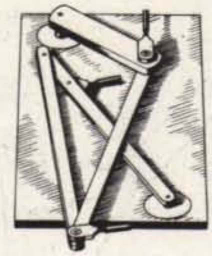
Substituting this expression for a in the equation derived previously for the output of the multiplier:

$$z = \frac{x}{b} \times y \times \frac{b}{d}$$

or:

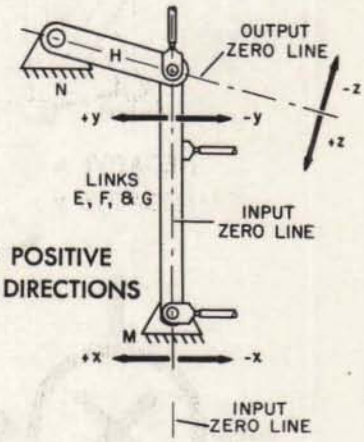
$$z = \frac{xy}{d}$$

Since d is a fixed distance for any multiplier, it is a constant that can be removed by means of a bell crank in the output, or simply by assigning a different value per unit of travel for the output link at the time of designing the instrument.



Negative Values

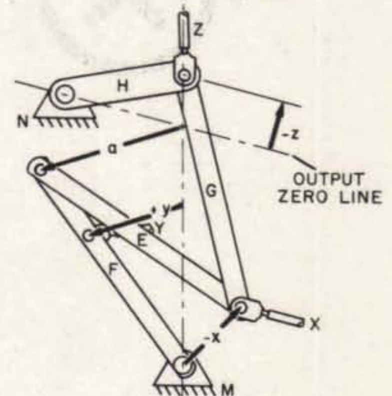
If movements of the two inputs to the left of the input zero line are considered to be positive values, negative inputs of x and y can be introduced by moving the respective links to the right of the input zero line.



ESTABLISHING POSITIVE AND NEGATIVE DIRECTIONS

Such a selection of positive and negative directions for the inputs will cause movements of Z below the output zero line to be positive, and movements of Z above the output zero line to be negative.

Assume that a negative x is to be multiplied by a positive y. Input link Y is moved a distance $+y$ to the left for a positive input. Input link X is moved a distance $-x$ to the right for a negative input. This causes output link Z to move above the output zero line a distance $-z$ for a negative output.



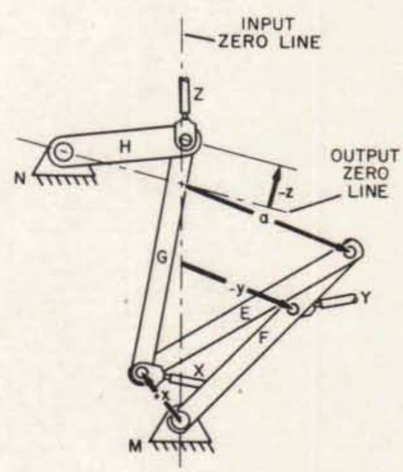
NEGATIVE x
POSITIVE y

Through the same analysis as described previously for the multiplication of positive values, it can be shown that the output, $-z$ in this case, is proportional to the product of $+y$ and $-x$. Stated mathematically:

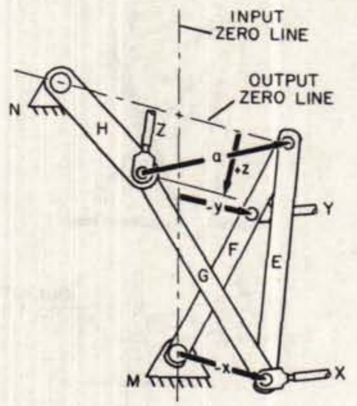
$$z=\frac{(-x)\,(+y)}{d}$$

Similarly, a negative y can be multiplied by a positive x. A negative y input moves input link Y to the right of the input zero line. Input link X moves to the left for a positive input, and output link Z moves above the output zero line for a negative output. The output is:

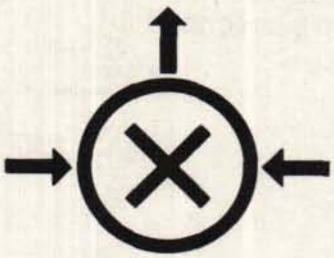
$$z=\frac{(+x)\,(-y)}{d}$$



POSITIVE x
NEGATIVE y



NEGATIVE *x*
NEGATIVE *y*



Since the product of two negative quantities is positive, negative inputs of both x and y will result in a positive output of z. Moving input links X and Y to the right for negative inputs will cause the output link Z to move below the output zero line for a positive output. The output in this case is:

$$z = \frac{(-x)\,(-y)}{d}$$

Distortion

Errors caused by distortion can be kept small by limiting the range of movement of the inputs.

Schematic Symbol

The schematic symbol for the XY linkage multiplier is a multiplication sign enclosed within a circle.

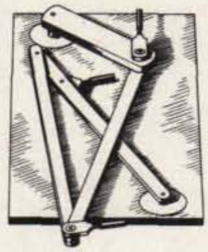
USING A MULTIPLIER AS A DIVIDER

The XY linkage multiplier can be employed as a divider. It has been shown that the XY linkage multiplier solves the following formula for z:

$$z = \frac{xy}{d}$$

This formula can be rearranged to give the following division equations, whose right-hand members express the division of one variable by another:

$$x = \frac{zd}{y} \quad \text{and} \quad y = \frac{zd}{x}$$



By reversal of input and output connections, the XY linkage can be made to solve either of these division equations.

For example, assume that the following division is to be performed:

$$x = \frac{zd}{y}$$

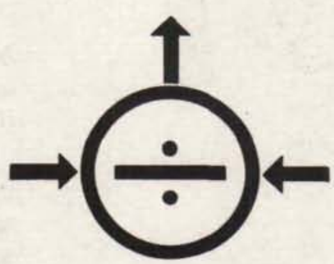
Link Z becomes an input link of the divider. It is positioned by the quantity to be divided (that is, the dividend). The other input, the divisor, positions link Y. The output, or quotient, is taken from link X.

Comparison with Other Dividers

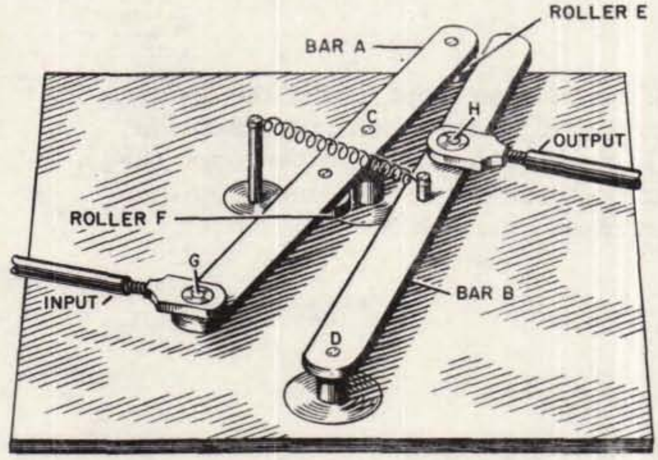
The XY multiplier, used as a divider, is unusual in respect to its simplicity. It is made of simple, easily constructed members with only pivot joints. It does not have sliding or screw members, or reciprocal cams. If the quantity used as the divisor does not approach zero, it requires no follow-up since its members are sufficiently rugged to withstand the driving forces. However, because of distortion errors, it is not an exact divider.

Schematic Symbol

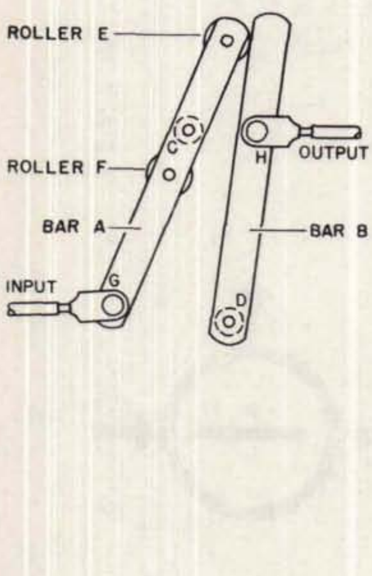
The schematic symbol for the linkage type divider is a division sign enclosed within a circle.



THE ABSOLUTER



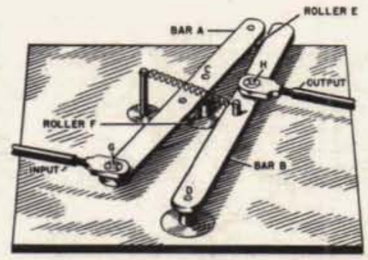
The absoluter consists of two bars, *A* and *B*, with pivots and links, somewhat resembling lever multipliers. Bar *A* has a fixed pivot at *C*, and bar *B* has a fixed pivot at *D*. Rollers *E* and *F* transfer motion from bar *A* to bar *B* by pushing against the side of bar *B*. A coil spring maintains continuous contact between bar *B* and the rollers on bar *A*. An input link and an output link are connected at points *G* and *H*, respectively.



The absoluter is a linkage mechanism that computes the absolute value, or magnitude, of a quantity, regardless of its sign. For example, the cardinal number 2 is the absolute value of $+2$ or -2. In the absoluter, negative and positive inputs cause the output to move in the same direction.

Motion of the input link to the left causes roller *E* to push against bar *B*, thereby moving the output link to the right a distance which is proportional to the input.

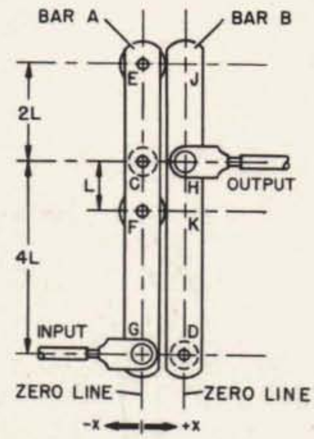
Motion of the input link to the right causes roller *F* to push against bar *B*, and likewise moves the output link to the right a distance which is proportional to the input.



How It Works

The absoluter may be considered as two lever multipliers working in series. Bar A is one of the levers, and bar B is the other. The two bars are of equal length.

Certain relations must exist among the distances between various points on these bars in order that input x shall have the same effect on the output for movement in either direction. Let L be the distance CF between pivot C and roller F. In the absoluter illustrated here, the distances between points on bars A and B have the following values in terms of the distance L. (Other absoluters may have different values but the relations among these values are the same.):

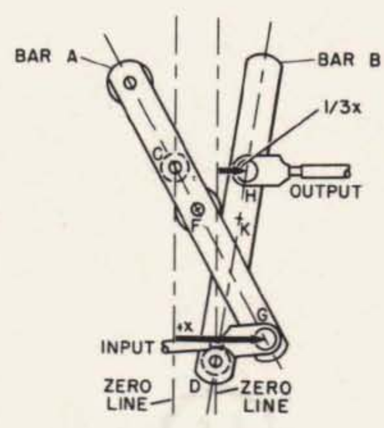


ZERO POSITION

Bar A	Bar B
$CF = L$	$HK = L$
$CE = 2L$	$HJ = 2L$
$CG = 4L$	$HD = 4L$

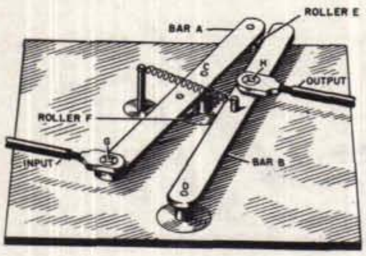
When the absoluter is at its zero position, the two bars, A and B, are parallel to each other, and the centers of all pivots and rollers lie on the input and output zero lines.

Assume that movements of the input link to the right of the input zero line represent positive values and that movements to the left are negative.



POSITIVE INPUT

To explain the operation of the absoluter, suppose that the input link is moved a distance $+x$ to the right of the zero line. Since bar A is pivoted at C, roller F pushes against bar B, causing the output link to move to the right.



Bar A forms a lever multiplier with arms CG and CF. A movement of $+x$ at point G causes point F to move a distance equal to $x \times \frac{CF}{CG}$.

Since: $CF = L$
And: $CG = 4L$

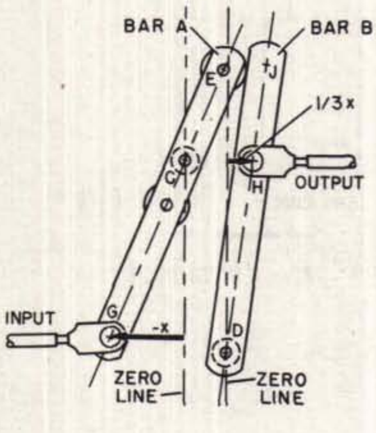
Then: movement at $F = x \times \frac{L}{4L} = \frac{x}{4}$

Quantity $\frac{x}{4}$, representing movement at F, forms the input to bar B at point K. Bar B forms a second lever multiplier with arms DH and DK. Therefore, movement of the output link is $\frac{x}{4} \times \frac{DH}{DK}$.

Since: $DH = 4L$
And: $DK = 4L - L = 3L$

Then: movement at $H = \frac{x}{4} \times \frac{4L}{3L} = \frac{x}{3}$

Consequently, the output of the absoluter equals one-third of the input, for positive values of the input.



NEGATIVE INPUT

Assume that the input link is moved a distance $-x$ to the left of the zero line. Roller E pushes against bar B, and the output link again moves to the right. In this case, the first lever multiplier is formed by arms CE and CG, and the movement at E is equal to $x \times \frac{2L}{4L}$, or $\frac{x}{2}$. Quantity $\frac{x}{2}$ is the input to the second lever multiplier formed by arms DH and DJ. The output of the absoluter is $\frac{x}{2} \times \frac{4L}{6L} = \frac{x}{3}$.

The output of the absoluter is therefore equal to one-third of the input in both cases.

Distortion

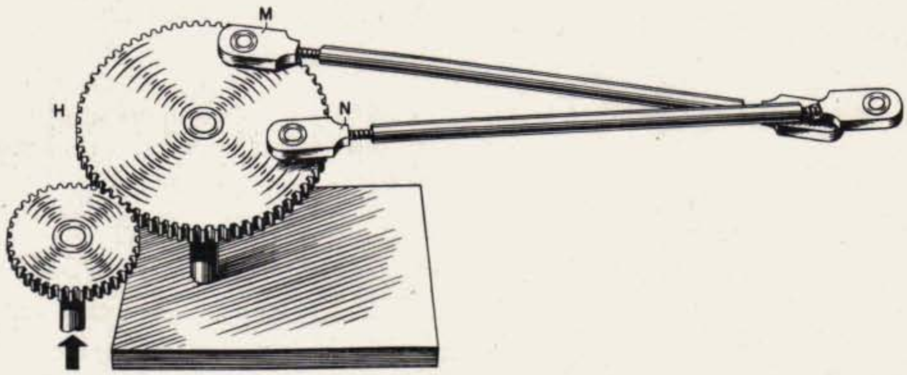
Distortion can be held to a minimum by limiting the range of movement of the input.

Schematic Symbol

The schematic symbol for the absoluter consists of two vertical lines enclosed within a circle.

ANGLE RESOLVERS

An angle resolver is a mechanism which computes the sine and the cosine of an angle.

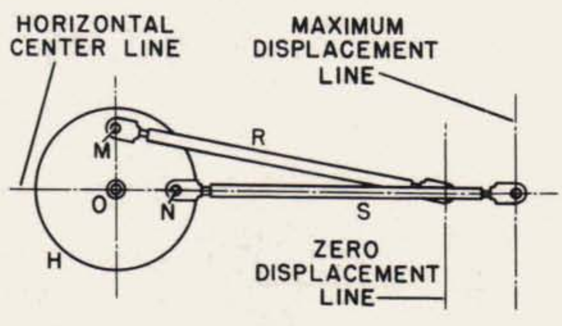


SIMPLE ANGLE RESOLVER

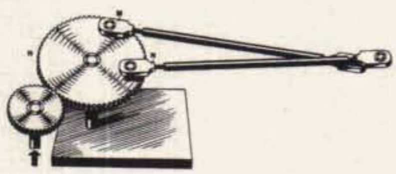
A simple resolver consists of a gear *H* on which two pins, *M* and *N*, are mounted 90 degrees apart and equidistant from the center of the gear. Attached to each pin is an output link which transmits the horizontal component of the motion of the pin as the gear rotates. The horizontal component of the displacement of pin *M* is proportional to the sine of the angle through which gear *H* rotates, and the horizontal component of the displacement of pin *N* is proportional to the cosine of the same angle.

How It Works

Assume that radius *OM* is perpendicular to the horizontal center line and that radius *ON* is on the horizontal center line. This is the zero position of the resolver; it is the position assumed by the mechanism when the angle to be resolved is zero.



ZERO POSITION



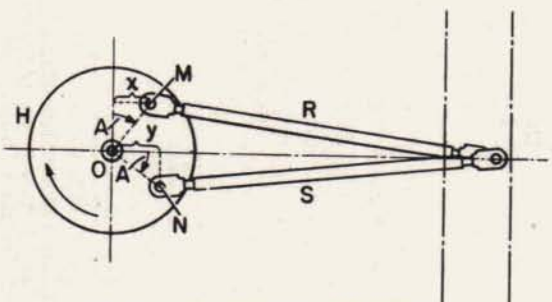
At the zero position, the sine of the angle is equal to zero and output link R is at its zero displacement position. Similarly, the cosine of the angle is equal to unity and output link S is at its maximum displacement.

If gear H is rotated in a clockwise direction through angle A, link R moves to the right and link S moves to the left.

The horizontal component of the displacement of pin M is distance x. From the right triangle formed with x as one side:

$$\sin A = \frac{x}{OM}$$

$$\text{or:} \quad x = OM \sin A$$



SINE AND COSINE OUTPUTS

Since OM is a constant, the distance x is proportional to sin A. Hence the displacement of output link R is proportional to sin A.

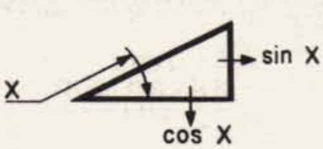
The horizontal component of radius ON is distance y. From the right triangle:

$$\cos A = \frac{y}{ON}$$

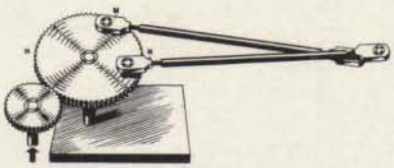
$$\text{or:} \quad y = ON \cos A$$

Therefore, the displacement of output S from the zero line is proportional to cos A.

Schematic Symbol



The schematic symbol for the angle resolver consists of a right triangle with an arrow across the angle being resolved. An arrow pointing outward from the opposite side represents the sine output, and an arrow pointing outward from the adjacent side represents the cosine output.



Distortion

If each output link were always parallel to the horizontal center line, motion of the output end of the link would be strictly proportional to the sine or cosine of angle *A*. However, this is not the case. Movement of the output end of each link, therefore, is not the same as the horizontal displacement of pin *M* or *N*.

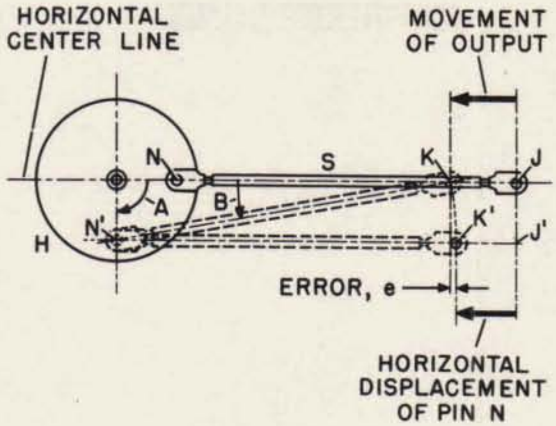
Let pin *N* be at the horizontal center line. Then output link *S* is parallel to the horizontal center line, and its output end is at *J*.

Now let angle *A* be increased so that pin *N* moves to *N'*. The output link will be positioned at angle *B* from the horizontal center line and its output end will be at *K*.

If the output end of the link is dropped from point *K* to point *K'*, so that the link is parallel to the horizontal center line, the horizontal displacement, *K'J'*, of the link will be equal to that of pin *N*. However, *K'J'* is less than the movement, *KJ*, of the output end when it travels along the horizontal center line. Thus the movement *KJ* is in error by an amount *e*. This is the maximum value; it decreases as angle *B* decreases, and is never very large if the proper relationship between the sizes of gear and link is selected.

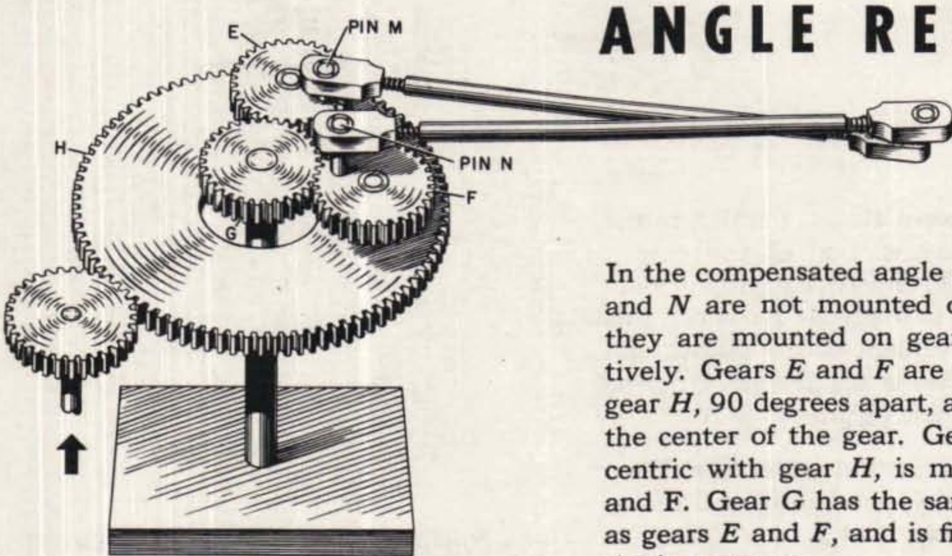
As angle *A* increases, the angle between the horizontal center line and the sine output link decreases, while the angle between the horizontal center line and the cosine output link increases. Therefore it can be stated that: the error in the sine output decreases and the error in the cosine output increases as angle *A* moves from zero to ninety degrees.

In the compensated angle resolver, these errors are reduced to a negligible value for the computation performed.



DISTORTION ERROR

THE COMPENSATED ANGLE RESOLVER

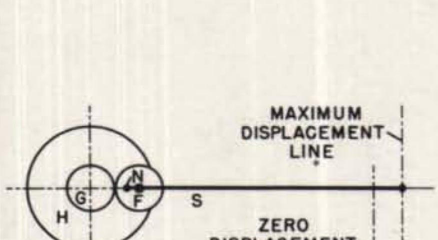


In the compensated angle resolver, the pins *M* and *N* are not mounted on gear *H*. Instead, they are mounted on gears *E* and *F*, respectively. Gears *E* and *F* are bearing mounted on gear *H*, 90 degrees apart, and equidistant from the center of the gear. Gear *G*, which is concentric with gear *H*, is meshed with gears *E* and F. Gear *G* has the same number of teeth as gears *E* and *F*, and is fixed to the frame of the instrument.

As gear *H* rotates, it carries gears *E* and *F* with it, causing them to roll around gear *G*. Pins *M* and *N*, consequently, change their positions relative to gear *H;* that is, they move in a circle about the centers of gears *E* and *F*. This added motion to the pins applies a correction to the output links which compensates for the error caused by the angle between the horizontal center line and the links.

How It Works

In the uncompensated resolver, the horizontal displacement of the output link *S* contains no error when the link lies on the horizontal center line. However, as the angularity of link *S* is increased, the right end of the link is pulled too far to the left, causing an error in the output.

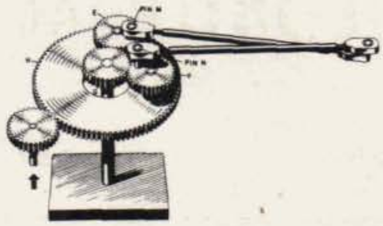


ZERO POSITION
FOR COSINE OUTPUT

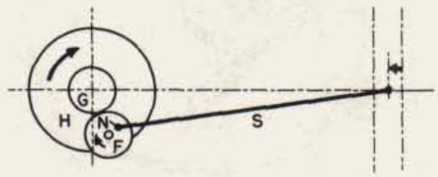
In the compensated resolver, the error at the output of link *S* is greatly reduced by shifting the location of pin *N* relative to gear *H*.

At the zero position, the center of gear *F* is on the horizontal center line and pin *N* is at the left of the center of gear *F*.

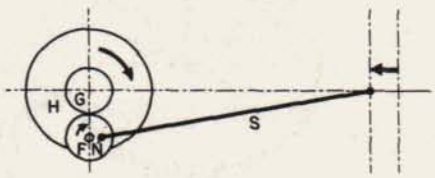
As gear H turns clockwise, rotation of gear F, due to its rolling around fixed gear G, moves pin N toward the right with respect to gear H. Movement of pin N toward the right introduces a correction that reduces the error caused by link S being too far to the left, as it was in the uncompensated resolver.



When gear H has turned clockwise through an angle of 90°, pin N has its greatest displacement to the right. Thus the correction increases as the angle between link S and the horizontal center line increases. The correction nearly balances the error, which increases with increasing angularity of link S.

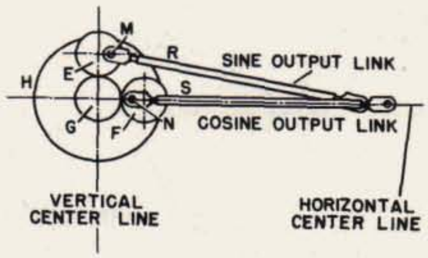


INPUT INCREASES



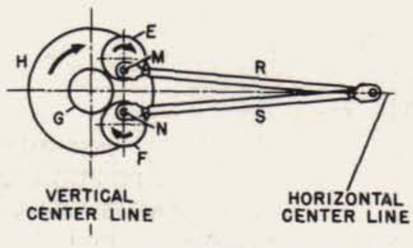
INPUT EQUALS 90°

Similarly, correction is made for the error at the output of link R, caused by the changing angle between link R and the horizontal center line. At the zero position, gear E is on the vertical center line and pin M is at the right of the center of gear E. The angle between link R and the horizontal center line tends to place the output end of link R too far to the left. This error, however, is compensated by right displacement of pin M.



ZERO POSITION

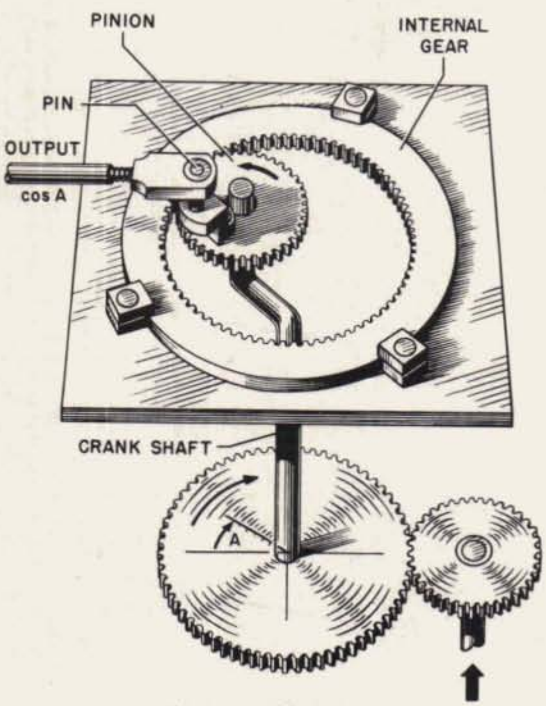
As angle A increases, pin M rotates about the axis of gear E and the correction decreases as the angle between link R and the horizontal center line decreases.



SINE AND COSINE OUTPUTS

The corrections introduced by shifting pins M and N do not completely compensate for the errors. These errors, however, are completely eliminated in the internal gear angle resolver.

THE INTERNAL GEAR ANGLE RESOLVER

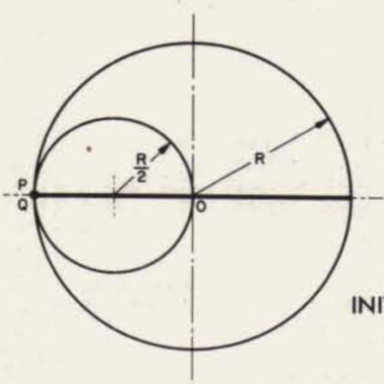


The internal gear angle resolver consists of two gears; an internal gear and a pinion. The pinion, which has half as many teeth as the internal gear, is bearing mounted on a crank shaft.

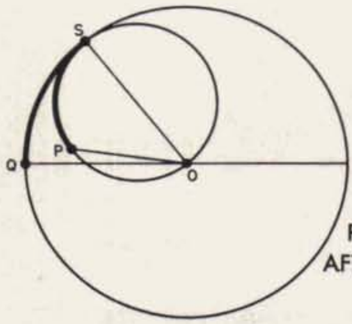
Rotation of the crank shaft causes the pinion to roll around the inside of the internal gear. A pin mounted near the periphery of the pinion moves the output link a distance proportional to the sine or the cosine of the angle through which the crank shaft is rotated.

This resolver computes true sine or cosine values. It is free from the distortion inherent in the other types.

How It Works



INITIAL POSITION OF POINT *P*



ASSUMED POSITION OF *P* AFTER SMALL CIRCLE HAS ROLLED TO POINT *S*

Assume that a point *P* is located on the circumference of a small circle rolling internally on another circle. As in the case of the pinion and internal gear, let the radius of the small circle be one-half the radius of the large circle. Under these two conditions, it can be shown that point *P* must move in a straight line along a diameter of the large circle.

The proof that point *P* moves along a diameter of the large circle is made by showing that no other path is possible. Initially, let point *P* of the small circle coincide with a point *Q* on the circumference of the large circle. A diameter drawn through the center *O* of the large circle to point *Q* establishes the stated path of point *P*. Secondly, let the small circle roll over an arc *QS* on the large circle. Then, as a matter of proof, assume that point *P* does not lie on line *QO*. However, it will be shown that this is a false assumption and that point *P* must lie on line *QO*.

To aid in this proof, a line is drawn from point O to the assumed position of point P and a second line is drawn from point O to the point of tangency, S, between the two circles. This construction forms angles POS and QOS. The proof is as follows:

1. Angle POS is an inscribed angle in the small circle. Therefore, according to a theorem of plane geometry, angle POS measured in degrees equals one-half arc PS measured in degrees.

2. Angle QOS is a central angle in the large circle. Therefore, angle QOS measured in degrees equals arc QS measured in degrees.

3. The linear lengths of arcs PS and QS are equal since they both are the distance traveled by the small circle. However, *measured in degrees*, arc PS is one-half arc QS because the radius of the small circle is one-half the radius of the large circle.

4. From the relations established in steps 1, 2, and 3, it follows that angle POS must equal angle QOS.

5. Since line OS is common to both angles and since the two equal angles overlay each other, lines PO and QO must coincide. Therefore, point P is on line QO, which extends to form a diameter of the large circle.

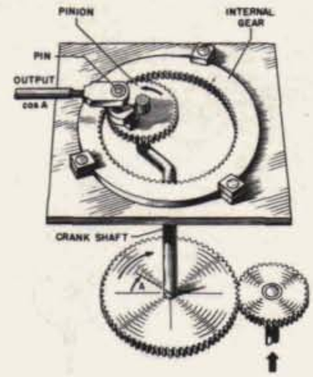
To analyze the displacement of point P along the horizontal diameter, assume that the small circle has rolled inside the large circle until the line joining the centers has moved through angle A. Point P lies at the intersection of the small circle and the horizontal center line. Lines joining points S, P, and O on the circumference of the small circle form a right triangle, with OS the hypotenuse; since an angle, like OPS, inscribed in a semi-circle is a right angle. Designate side OP, the distance of point P from the vertical center line, as x. Then:

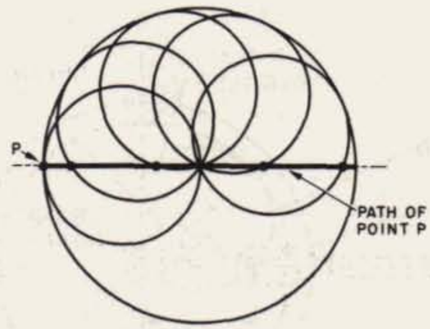
$$x = OS \cos A$$

Since OS is a constant, distance x is proportional to the cosine of angle A. Hence:

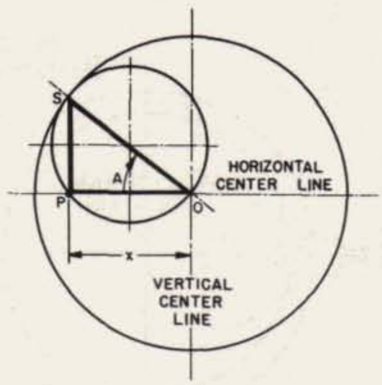
$$x = K \cos A$$

where K is a constant.

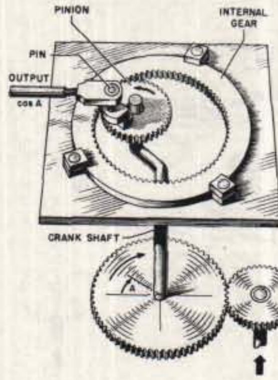




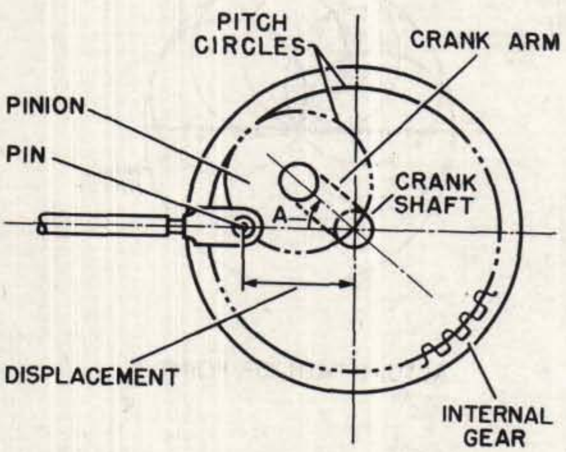
ACTUAL PATH OF POINT *P*



x IS PROPORTIONAL TO COSINE *A*

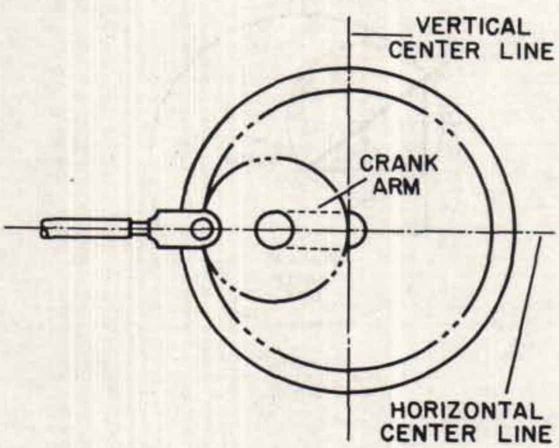


The circles of the illustrations that show how the internal gear angle resolver works meet the definition of pitch circles, which are circles that roll together with the same ratio as a pair of gears built upon them. The large circle represents the pitch circle of the internal gear of the actual mechanism, and the small circle represents the pitch circle of the pinion. Point *P* on the small circle represents the pin located over the pitch circle of the pinion.



ROLLING CIRCLES CORRESPOND TO PITCH CIRCLES

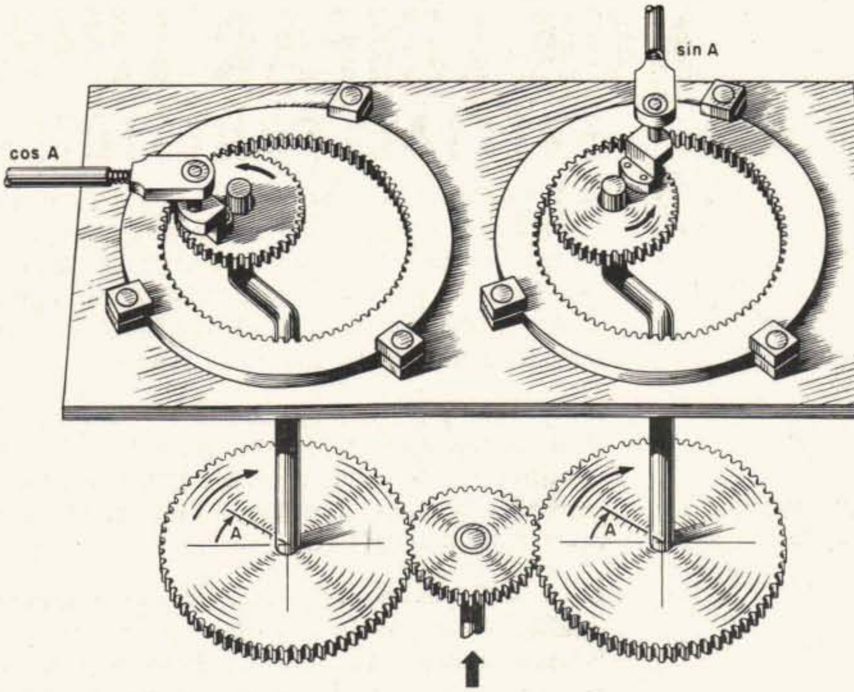
As the pinion, driven by the crank shaft, rolls around the inside of the internal gear, the pin moves in a straight line along a diameter of the internal gear, and the displacement of the output link is proportional to the cosine of the angle through which the crank shaft is rotated.



ZERO POSITION

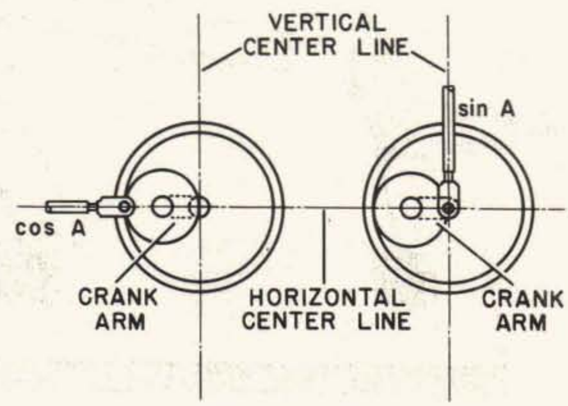
With angle *A* at zero, the crank shaft is so positioned that the crank arm is at the horizontal center line, and the output link is at its maximum displacement position to the left of the vertical center line. This corresponds to the value of unity for cos *A*.

As angle *A* increases, the output link moves to the right, its displacement from the vertical center line being proportional to the cosine of angle *A*.



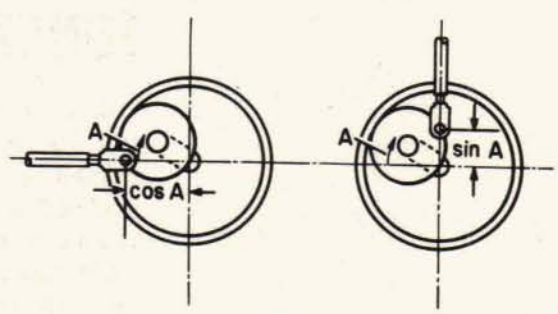
COMBINED SINE AND COSINE RESOLVERS

By gearing a second resolver to the first, and by positioning the output link and pinion differently in the second resolver, the sine of angle *A* can also be computed.



ZERO POSITION

With angle *A* at zero, the crank arm of the sine mechanism, like that of the cosine mechanism, is aligned with the horizontal center line; but the output link is at its zero displacement position. This zero position is the intersection of the horizontal and vertical center lines.

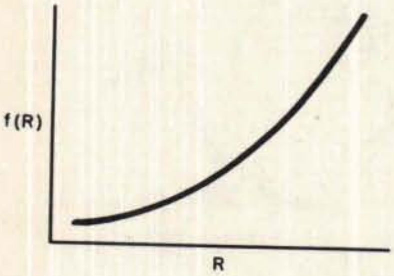


WITH ANGULAR INPUT

As angle *A* increases, the inside pinion turns counterclockwise. This causes the sine output link to move upward along the vertical center line, by an amount proportional to the sine of angle *A*.

NON-LINEAR LINKAGES

SPECIAL FUNCTIONS

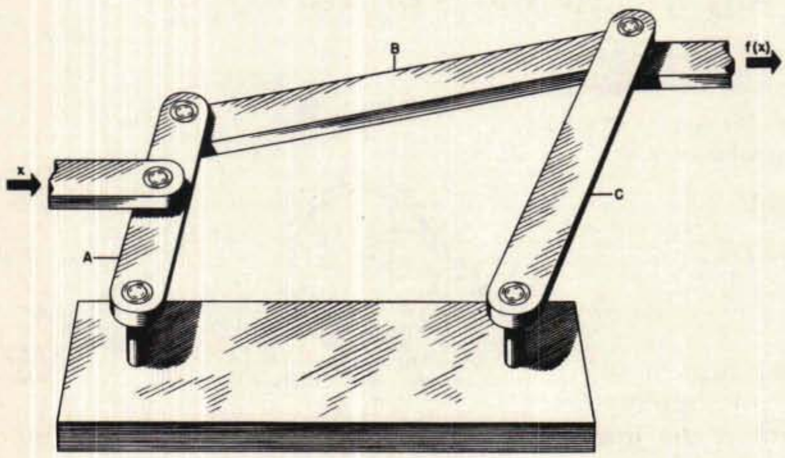


PLOT OF EMPIRICAL DATA

In the solution of a fire control problem, some data must be computed which cannot conveniently be expressed by a simple mathematical relationship. This data cannot, for example, be expressed as easily as the sine of an angle, or as the sum or product of several quantities. Empirical data of this type may be described by means of graphs.

As an example, assume a curve, plotted from empirical data, showing the variation of the quantity $f(R)$ with range. The variation is such that as range increases, the quantity $f(R)$ increases, but not according to any relation that can be expressed by a simple equation.

Since $f(R)$ cannot be expressed by a simple equation, the linkage mechanisms described previously cannot be used. Special linkage mechanisms, however, can be designed to generate complicated functions of an input variable.

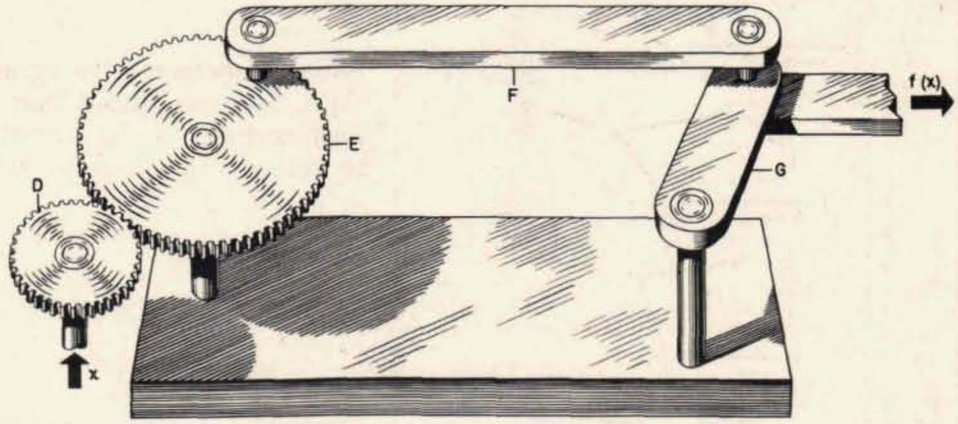


NON-LINEAR FUNCTION MECHANISM

FUNCTION MECHANISMS

One of the simplest function mechanisms consists of three links, *A, B,* and *C*. The lower ends of links *A* and *C* are connected to fixed pivots and the upper ends are connected to each other through link *B*. The input is carried through links *A* and *B* to the output link. The function computed depends upon the point on link *A* at which the input link is located and also upon the lengths and arrangement of the individual links.

The same function can be computed for angular movements of the input by replacing the input link and link *A* with two gears, *D* and *E*. The input drives through gears *D* and *E* while a pin on gear *E* drives the output link through link *F*. The function computed depends upon the choice of gear and linkage dimensions.



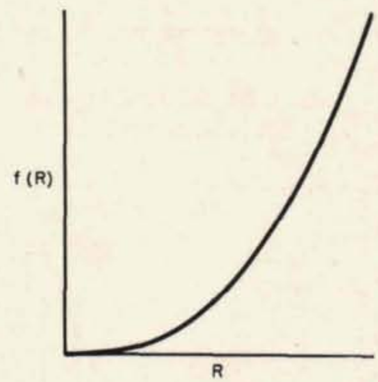
ANOTHER ARRANGEMENT

How It Works

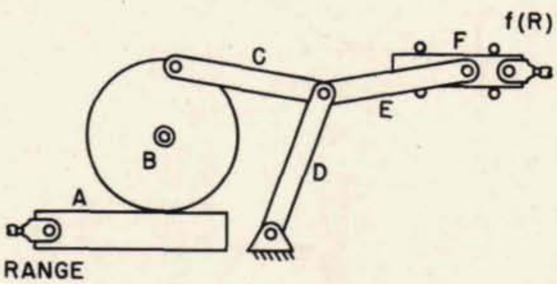
Assume that a curve has been plotted showing the variation, with range, of the quantity $f(R)$.

Also assume that a function mechanism has been selected to compute $f(R)$. Non-linear linkage mechanisms have been classified and the general types of functions computed by these mechanisms have been determined. From this classification, a particular mechanism can be selected to approximate $f(R)$. Then, by trial and error, the dimensions of links can be altered until the selected mechanism accurately computes $f(R)$.

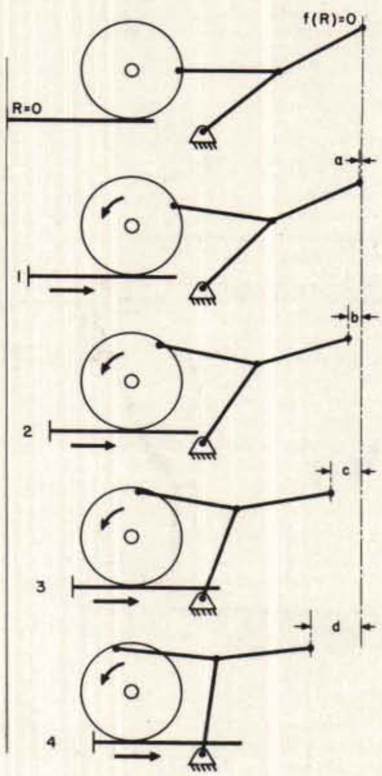
In this case, the selected mechanism consists of rack *A*, gear *B*, links *C*, *D*, and *E*, and a guided bar *F*. The input is introduced at rack *A*, which, in turn, drives gear *B*. A pin on gear *B* drives links *D* and *E* through link *C*. Link *E* moves bar *F* between guide rollers. An input link connects with rack *A* and an output link connects with bar *F*.



CURVE SHOWING *f(R)*



MECHANISM FOR COMPUTING *f(R)*

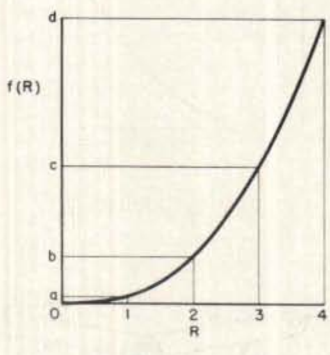


OUTPUT OF MECHANISM
FOR INCREMENTS OF *R*

With range at zero, the input link is at its extreme left position and the output link is at its extreme right position.

As range increases, the input link moves to the right, and the output link moves to the left. Displacement of the output link to the left of its zero position represents the quantity $f(R)$.

Successive increases in range cause further increases in $f(R)$.

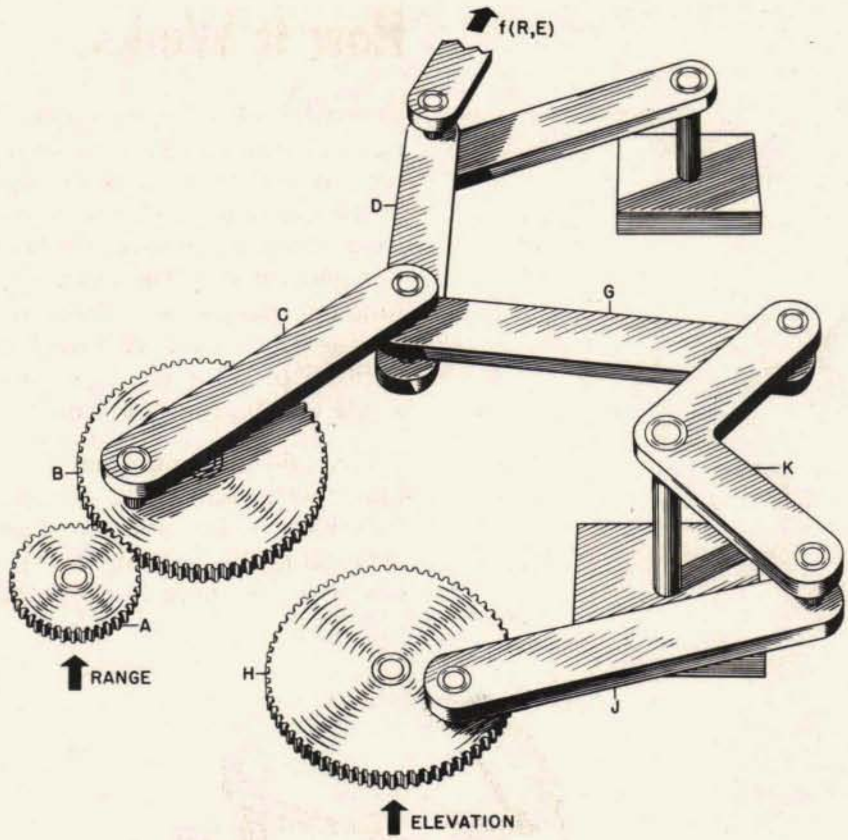


PLOT OF MECHANISM
OUTPUT

By plotting the values of the output link against the respective input values, a curve showing the increase in $f(R)$ with range is obtained. The shape of the curve is essentially the same as that of the original $f(R)$ curve. By the proper choice of gear and linkage dimensions, the mechanism can be designed so that its output is an extremely close approximation of the correct value of $f(R)$.

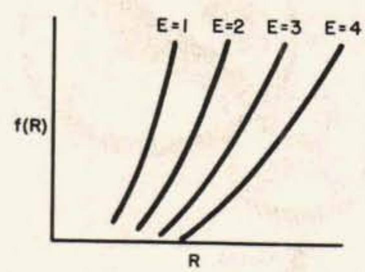
Schematic Symbol

The schematic symbol for the function mechanism consists of the lower case letter "f" enclosed in a circle.



COMPOUND FUNCTION MECHANISMS

Some of the special quantities used in the solution of a fire control problem are functions of two independent variables. For example, the quantity $f(R,E)$ is a function of both range and elevation. This function is shown graphically by means of a family of curves. Each individual curve represents values of $f(R)$ for all values of range at one elevation only. Separate curves are plotted for different elevations. The entire family of curves shows $f(R,E)$.



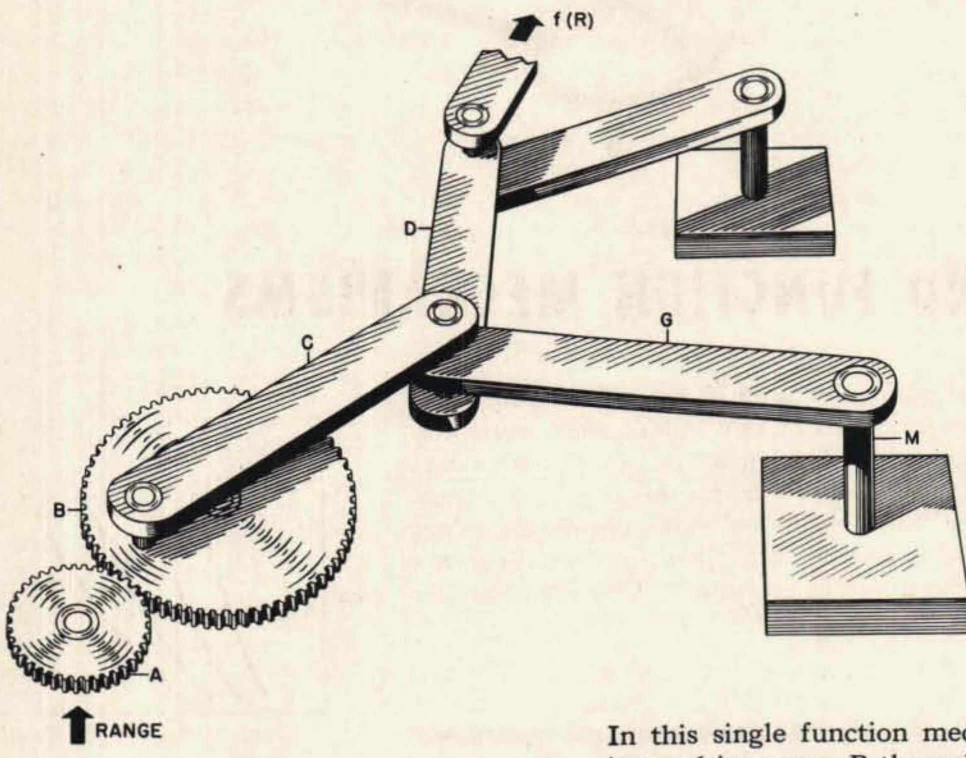
FAMILY OF CURVES SHOWING $f(R,E)$

Two single function mechanisms can be combined to compute the function represented by a family of curves. This combination is called a compound function mechanism. Such a mechanism has two inputs, each computing a part of the function. These two parts of the function are combined within the mechanism to produce the compound function.

How It Works

The value of a function generated by a single function mechanism depends not only upon the lengths of the links but also upon the locations of the fixed pivots. If the location of one of the fixed pivots is changed, the values of the function generated will also change. The compound function mechanism works on this principle; that is, the output is varied by changing the position of what would be a fixed pivot in a single function mechanism.

To explain the operation of a compound function mechanism, first assume that a single function mechanism has been designed for generating the quantity $f(R)$, values of which describe one curve in the family of curves for $f(R,E)$.

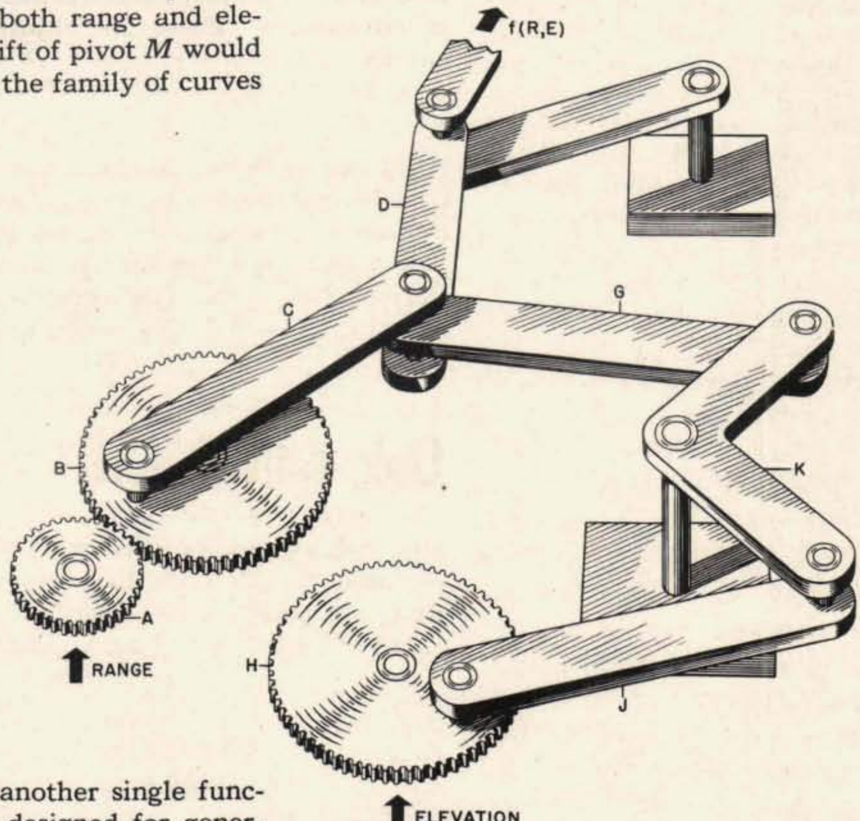


SINGLE FUNCTION MECHANISM

In this single function mechanism, the range input drives gear *B* through gear *A*, while an eccentric pin on gear *B* drives the output link through links *C* and *D*. Link *G*, pivoted at point *M*, guides the movement of links *C* and *D*, thereby determining the values of $f(R)$.

If fixed pivot M could be shifted to another point, a different set of values could be generated. These values could represent some other curve in the family of curves for $f(R,E)$.

Furthermore, if pivot M could be shifted to various positions representing values of $f(E)$, movement of the output link could represent the combined function of both range and elevation, or $f(R,E)$. Each shift of pivot M would represent another curve in the family of curves for $f(R,E)$.

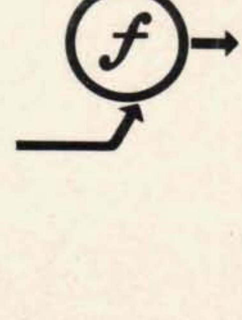


COMPOUND
FUNCTION MECHANISM

Accordingly, assume that another single function mechanism has been designed for generating the quantity $f(E)$. This mechanism consists of gear H, link J, and bell crank K. The output end of bell crank K is connected to link G in place of fixed pivot M. Changes in elevation shift the pivot at the lower end of link G in accordance with values of $f(E)$. This causes movement of the output link of the compound function mechanism to represent values of the quantity $f(R,E)$.

Schematic Symbol

The schematic symbol is similar to that for the single function mechanism except that there are two inputs to the mechanism instead of only one.



LINKAGE ADJUSTMENTS

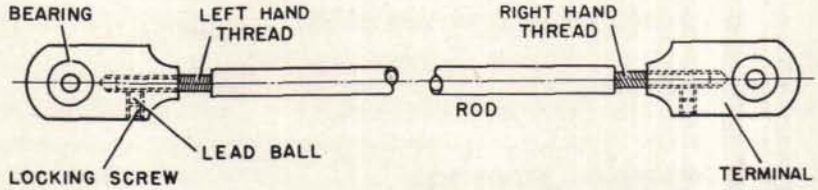
The use of clamps for adjustment of gearing was discussed in Section 1. Linkage mechanisms use two additional means of adjustment. These are adjustable links and adjustable cranks.

A measuring device to check the adjustment of a linkage is commonly provided by two accurately located holes having the same diameter. One hole is in the mechanism to be adjusted and the other hole is either in another link or in a stationary member. The correct adjustment is obtained when a setting rod can be inserted through both holes.

Link Adjustment

One linkage mechanism can be adjusted to another linkage mechanism by varying the distance between pivots in a link that connects the two mechanisms. This distance can be changed by the use of an adjustable link.

An adjustable link consists of a rod, threaded at both ends, and of terminals that screw on to the ends of this rod. Each terminal contains a bearing. One end of the rod has a right-hand thread and the other a left-hand thread.

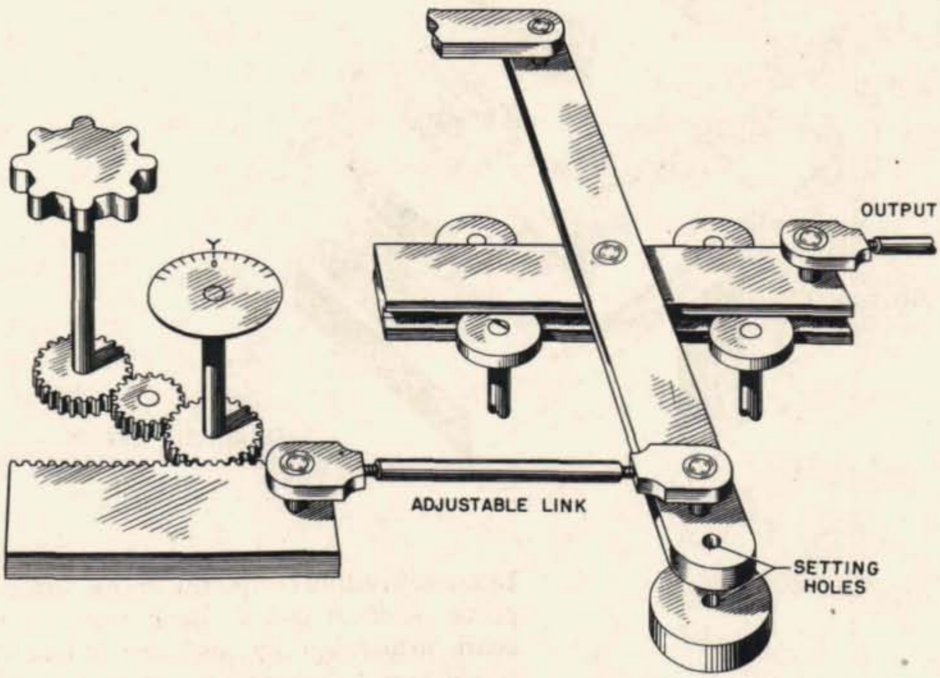


ADJUSTABLE LINK

The action of the adjustable link is similar to that of a turnbuckle. The right-hand and left-hand threads on the rod make it possible to vary the distance between terminals. Rotating the rod in one direction causes both threaded ends to screw into the terminals, so that the distance between the terminals decreases. Rotating the rod in the opposite direction causes the ends of the rod to back out of both terminals, thereby increasing the distance between terminals.

A locking screw threaded into the side of each terminal is used to secure the rod after an adjustment has been made. A lead ball between the locking screw and the rod prevents injury to the threads on the rod.

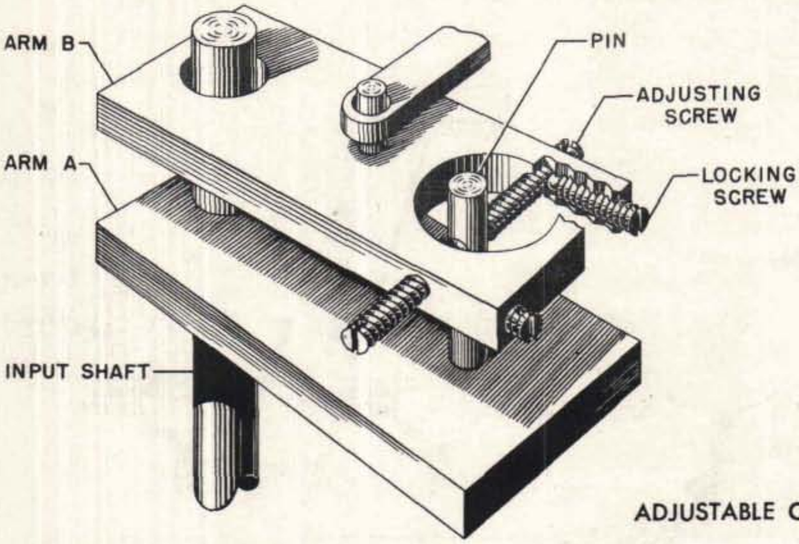
APPLICATION OF ADJUSTABLE LINK



As an example of how the adjustable link is used, assume that a linkage differential is to be adjusted to its zero position. One input to the differential is connected to another linkage mechanism by means of a non-adjustable link, and it is assumed that this mechanism is at its zero position. The second input is connected to a dial and a knob by means of gears, a rack, and an adjustable link. The adjustment consists of setting the adjustable link so that the differential is at its zero position when the dial is at zero. The dial merely indicates the zero position of the knob input. The zero position of the differential is obtained when a setting rod can be inserted through a hole in the differential and a hole in the instrument frame.

Crank Adjustment

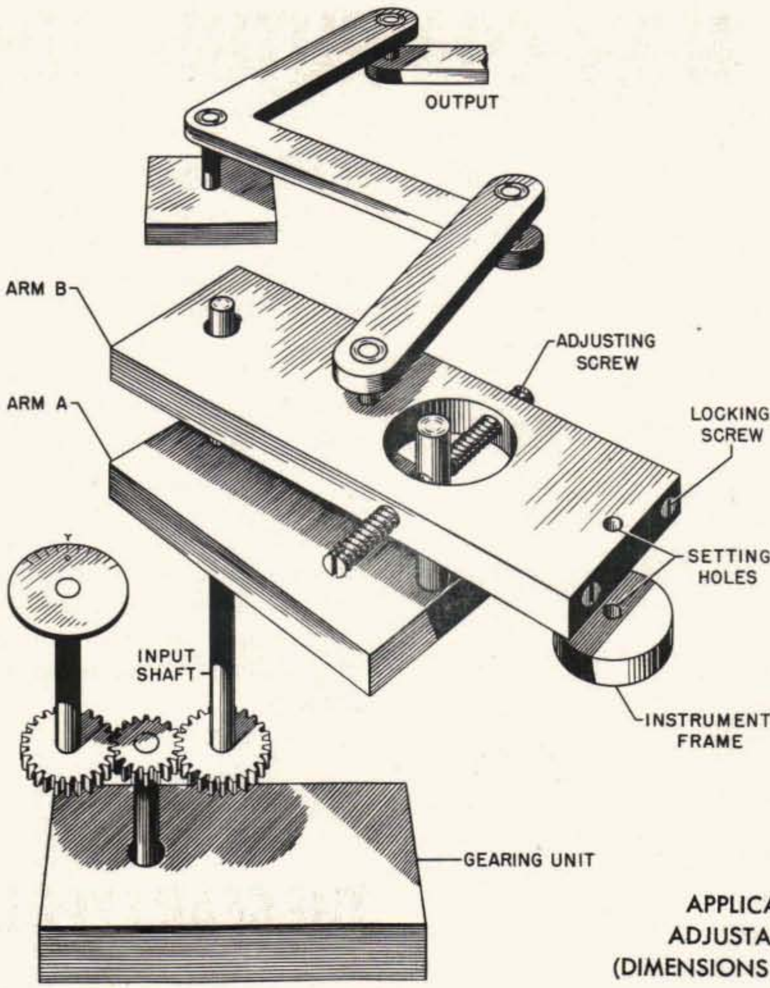
Transfer of shaft rotation to linkage movement can be accomplished by means of a crank. Adjustment between the shaft and the linkage can be made by an adjustable crank, which permits changing the angular relationship between the shaft and the crank.



ADJUSTABLE CRANK

In an adjustable crank, the crank arm consists of two separate parts: arms *A* and *B*. Both arms are mounted on the input shaft; arm *A* solidly, and arm *B* loosely. A pin, fixed to the top of arm *A*, is positioned in an opening in arm *B*. Adjusting screws on each side of the opening bear against the pin, causing the two arms to act as a single crank arm. Locking screws are used to secure the adjusting screws. A lead ball under each locking screw prevents injury to the thread of the adjusting screw. The output link is connected to the top of arm *B*.

The outer end of arm *B* can be moved relative to arm *A* by unscrewing one of the adjusting screws and by turning the other one in. Since arm *B* is mounted loosely on the input shaft, it can be rotated on the shaft relative to arm *A*. The amount of rotation is limited by the size of the opening in arm *B*.



APPLICATION OF ADJUSTABLE CRANK (DIMENSIONS EXAGGERATED)

To illustrate the use of the adjustable crank, assume that a linkage mechanism is to be adjusted to a gearing unit. A dial which is geared to the crank input shaft indicates the value represented by the position of the shaft. The adjustment consists of bringing the linkage mechanism to the position where a setting rod can be inserted through a hole in arm *B* and a hole in the frame of the instrument, with the dial held at a prescribed value.

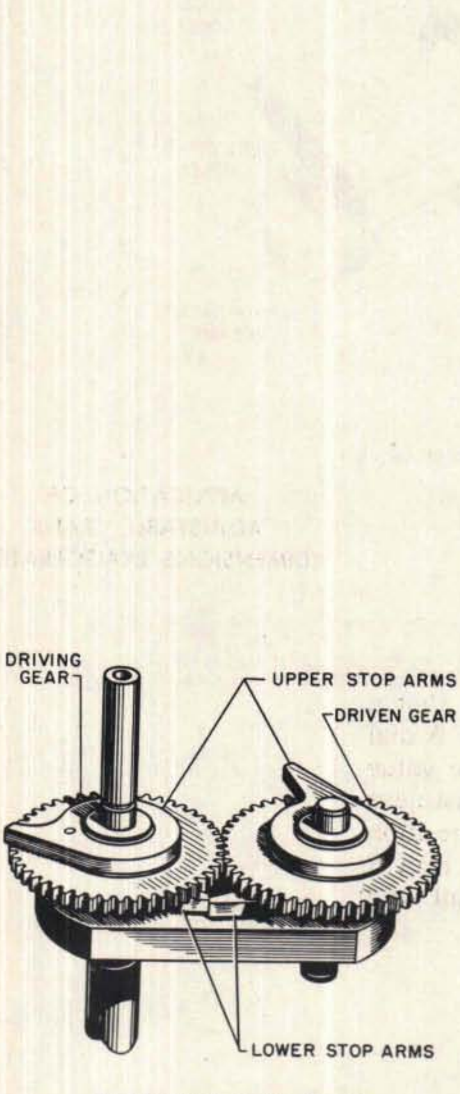
NON-COMPUTING LINKAGES

Linkage mechanisms, as in the case of other types of computing mechanisms, require safety devices to limit the movements of the various elements. These safety devices consist of limit stops, intermittent drives, and relief drives.

One type of limit stop and one type of intermittent drive are described in Section 2. An additional type of each is described here. A description of the relief drive, which may be considered as a linkage type of intermittent drive, is also included. The limit stop, intermittent drive, and relief drive described here are not only used with linkage mechanisms but may also be used with other types of computing devices.

THE GEAR TYPE LIMIT STOP

Gear type limit stops serve the same general purpose as the screw type limit stops described on page 144.

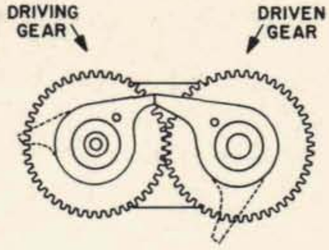


GEAR TYPE LIMIT STOP

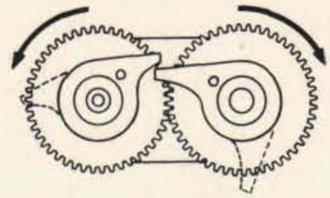
The gear type limit stop consists of two pairs of stop arms and two meshing gears of unequal size. One stop arm is pinned separately to each face on each gear, forming a pair of stop arms above, and another below, the two gears. One arm of each pair is longer than the other. The longer arm is pinned to the larger gear. One pair of arms stops the rotation of the gears in one direction when the end faces of the two arms meet. Rotation of the gears in the opposite direction is stopped by the other pair of stop arms. The number of revolutions that the drive gear can turn before it is stopped depends upon the gear ratio and upon the relative positions of the stop arms on the gears.

How the Stop Operates

Suppose, initially, that the ends of the upper stop arms are touching. At this stop position (limit *A*), engagement of the upper arms limits rotation in one direction. However, the gears can rotate in the opposite direction since the lower stop arms are apart.

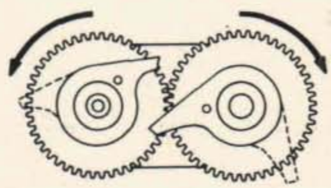


AT LIMIT A



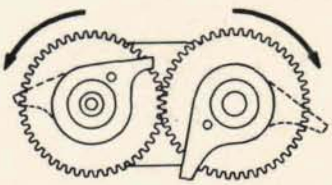
ONE TURN FROM LIMIT A

Now, suppose that the small (driving) gear turns one revolution from limit *A*. The large (driven) gear turns with the small gear, but the large gear does not turn through a complete revolution because it has more teeth than the small gear. This gives the arm on the small gear a greater rotational movement than the arm on the large gear. Because of this difference in movement and because of the shape of the arms, the upper arms are sufficiently apart at the end of one revolution to clear each other.



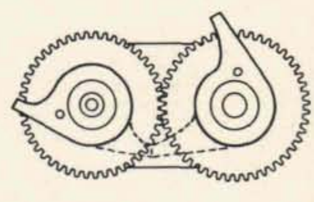
SIX TURNS FROM LIMIT A

As the two gears revolve, the difference in rotational movement increases. Consequently, the upper arms move farther apart. At the same time, the lower arms move closer together.



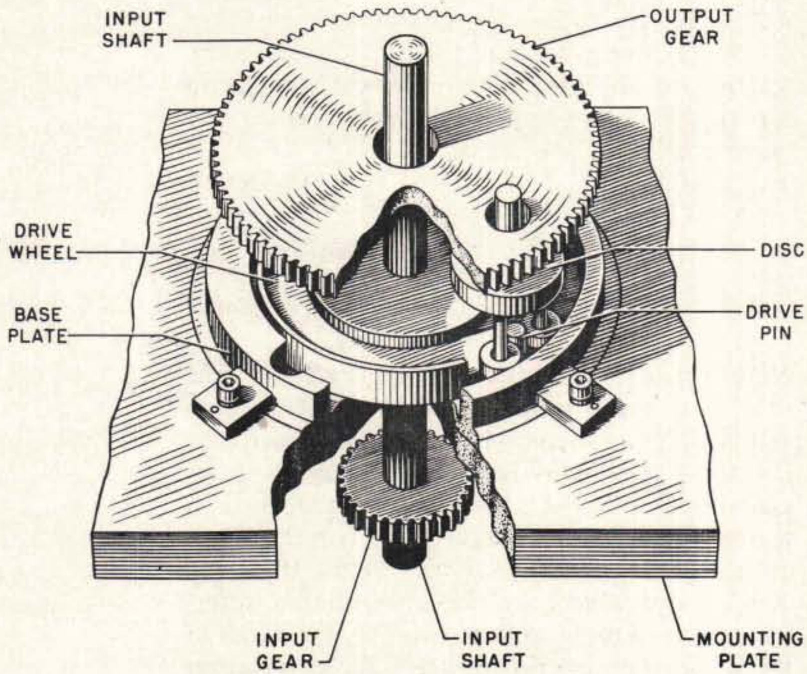
TWELVE TURNS FROM LIMIT A

After a number of revolutions, depending on the gear ratio and the angular spacing of the arms, the ends of the lower arms meet and stop rotation at limit *B*. However, the upper arms are now apart so that the gears can be rotated back to limit *A* again.



AT LIMIT *B*
($12\frac{1}{3}$ TURNS FROM LIMIT *A*)

THE INTERMITTENT DRIVE



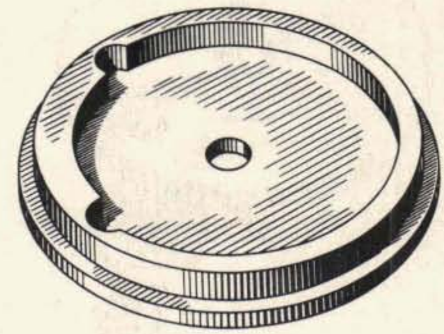
The function of an intermittent drive is described on page 146. A particular type of intermittent drive is also shown on that page. The description following page 146 shows that this type of drive permits many turns of its input and output shafts while the two shafts are connected, and also permits many additional turns of the input shaft while the output shaft is disconnected and locked. The type of drive shown there is particularly adaptable for use with a mechanism, such as a component solver, that requires many turns of the connecting shafts.

Another type of intermittent drive is illustrated here. This type differs from the type shown on page 146 in that its input and output shafts are connected for less than one revolution, and its input shaft is free to turn for less than one revolution after the output shaft has been disconnected and locked. It is adaptable for use in shaft lines which move through small angles, such as those which operate linkage mechanisms.

HOW THE DRIVE OPERATES

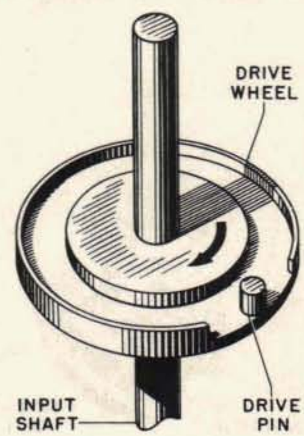
Driving the Output Gear

1. The input shaft moves a drive pin. The stationary base plate, which is clamped to a mounting plate, has a centrally located bearing. This bearing supports the input shaft so that the shaft can turn freely.



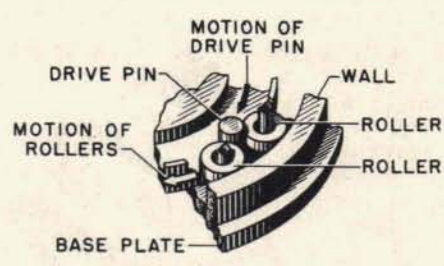
STATIONARY BASE PLATE

A drive wheel is secured to the input shaft. As the input shaft turns, it rotates the drive wheel. A drive pin is mounted near the edge of this wheel.

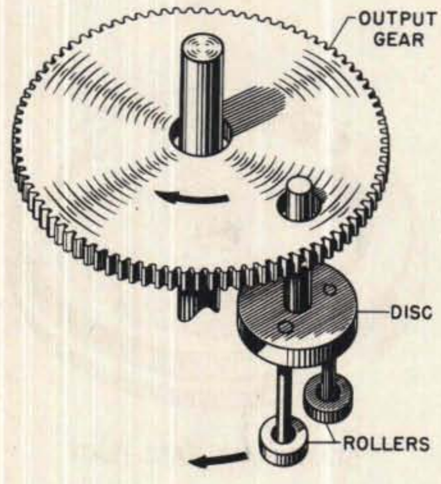


FROM INPUT SHAFT TO DRIVE PIN

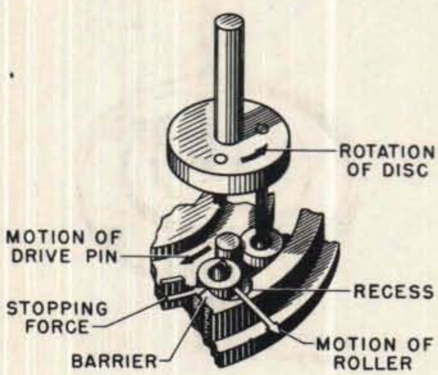
2. The drive pin acts against two rollers. The drive pin is confined between two rollers. It pushes against them, causing the rollers to move around a cylindrical wall on the base plate.



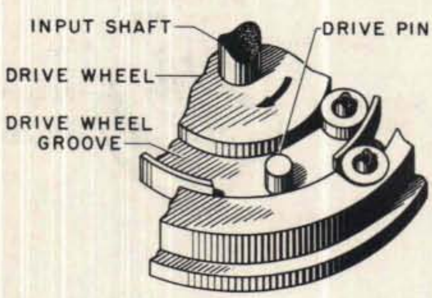
FROM DRIVE PIN TO ROLLERS



FROM ROLLERS TO OUTPUT GEAR



TRANSFER FROM DRIVE POSITION TO CUTOUT



INPUT SHAFT CAN TURN

3. The rollers transfer motion of the drive pin to the output gear. The two rollers are attached to a disc which, in turn, is bearing-mounted on the output gear. Through this arrangement the drive pin, by pushing against the rollers, causes the output gear to turn with the input shaft.

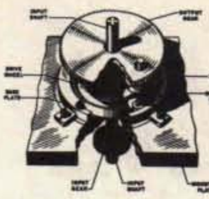
Cutout Action

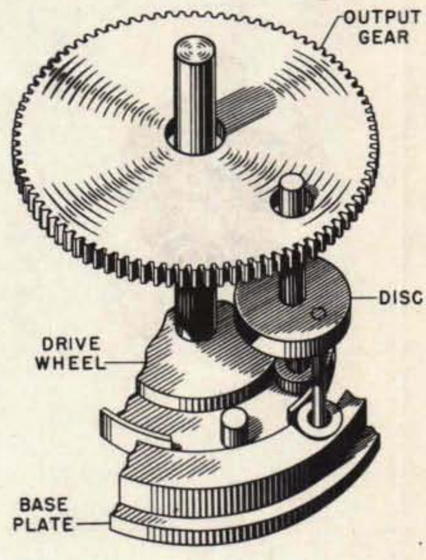
1. The rollers are stopped by a barrier. The cylindrical wall on the base plate has a barrier formed by an increase in the wall thickness. When a roller strikes this barrier, it cannot travel farther around the wall. However, adjacent to this barrier is a recess into which the striking roller can enter.

2. The disc rotates. The drive pin, pushing against the side of the roller which has struck the barrier, forces the roller into the recess in the base plate wall. This movement of the roller makes the disc rotate about its pivot. As the disc rotates, it carries the second roller around the drive pin to a position nearer the center of the drive wheel.

3. The input shaft is free to turn. With one roller in the recess and the other roller behind the drive pin, the drive pin is free of the rollers. Consequently, the drive wheel and input shaft can continue rotation without interference.

4. The output gear is locked. The roller confined in the recess in the stationary base plate cannot move. Consequently the output gear which supports this roller cannot turn. However, this locking action is positive only if the roller remains in the recess. To keep the roller there, the disc must be prevented from rotating back to its original position. This is accomplished by confining the inner roller within a groove cut into the drive wheel. On each side of the drive pin, the outer wall of this groove has been cut away. This cut-away portion allows the disc to carry the inner roller into alignment with the groove. Continued rotation of the drive wheel completely confines the roller within the groove so that the disc can no longer turn, thus the outer roller is locked within the recess in the base plate.

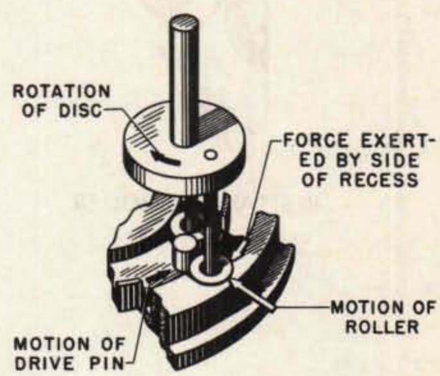




OUTPUT GEAR IS LOCKED TO BASE PLATE

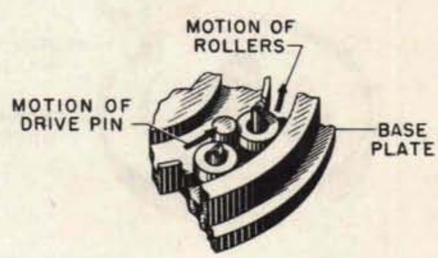
Returning to the Drive Position

1. The drive pin strikes a roller. If rotation of the input shaft is reversed, the drive pin moves back to the cutout position and strikes the roller that was confined in the drive wheel groove.



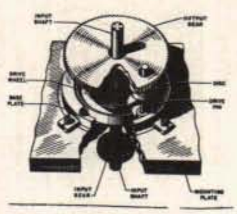
TRANSFER FROM CUTOUT TO DRIVE POSITION

2. The disc rotates. The force exerted by the drive pin and the force exerted by the side of the recess create a turning effort which rotates the disc back to the drive position. Rotation of the disc aligns the rollers with the wall of the base plate. The drive pin is now between the rollers.



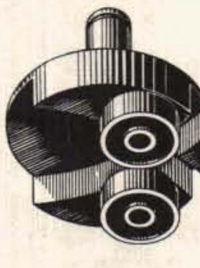
DRIVE POSITION

3. The output gear is driven by the input shaft. The drive pin pushes against the rollers, driving them around the base plate wall. This motion is transferred to the output gear, as described previously.



LIMITS OF OPERATION

The angle through which the output gear is able to rotate is limited to the angle between the two recesses, or cutout points, in the base plate. This angle, therefore, is dependent on the design of the base plate.



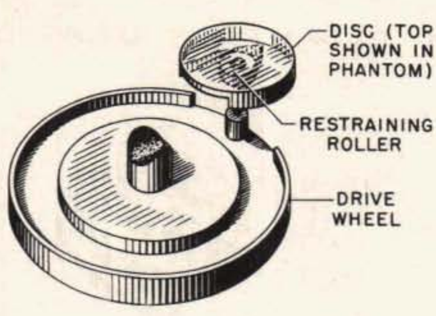
RECESS IN DISC

REFINEMENTS OF DESIGN

For simplicity of description, nothing has been said thus far about features of the intermittent drive that are not basically essential. These features serve primarily to improve the smoothness with which the drive cuts out, by preventing interference between the wall of the drive wheel groove and the roller that enters this groove.

RESTRAINING ROLLER

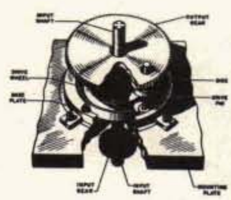
The features involved are (1) a recess in the face of the disc, and (2) a restrainer (a roller mounted on the drive pin). The recess is shaped like a V, except that the side walls are curved rather than straight. Slots extending from the bottom of the V are non-functional, being merely tool clearance incident to machining. The restrainer acts in the recess in the disc.

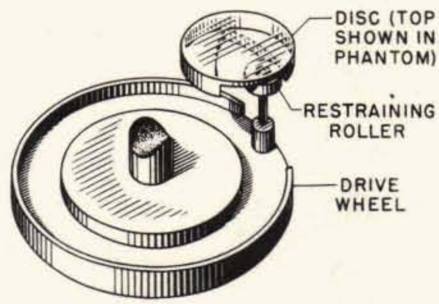


DRIVE POSITION

While the disc is in the drive position, the open end of the V-shaped recess faces the input shaft, and the restrainer bears against the sides of the V.

At cutout position, the disc is rotated so that one roller is in the recess of the base plate. After cutout, the drive pin moves beyond this roller, losing contact with it. This action starts before the outer wall of the drive wheel groove has confined the other roller. Therefore, at this time, the drive wheel groove cannot restrain the disc from turning back toward the drive position. The restrainer does, however, perform this function.



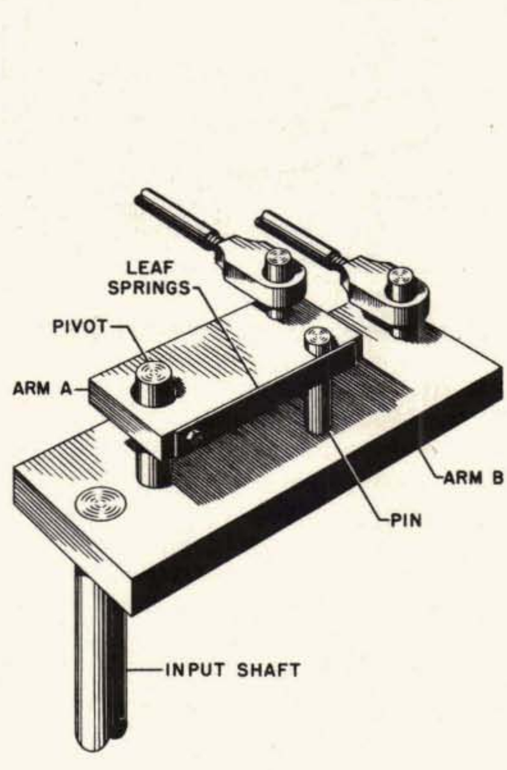


CUTOUT POSITION

With the disc at the cutout position, the V-shaped recess is oriented so that its open end faces in the direction of drive wheel motion, and so that one of its curved sides is parallel to the drive wheel rim. The restrainer maintains contact with the curved wall of the V and holds the disc at the cutout position. Hence, the roller is kept in alignment with the drive wheel groove, eliminating the possibility of the drive wheel wall striking the roller.

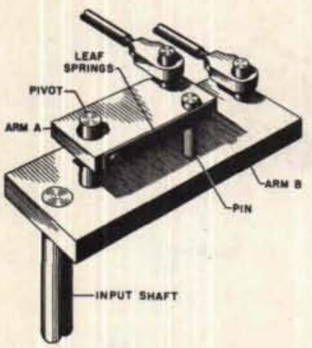
THE RELIEF DRIVE

The relief drive may be considered as a linkage type of intermittent drive which provides relief in one direction only.

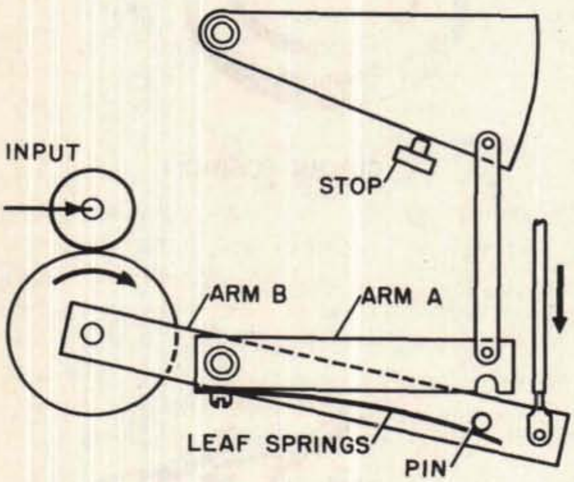


RELIEF DRIVE

The relief drive consists of a spring-loaded crank arm, *A*, supported on an ordinary crank arm, *B*. Arm *B* is secured to the input shaft. The inner end of arm *A* pivots on arm *B*. A pin attached to arm *B* fits a recess in the side of arm *A*. Leaf springs, fixed at one end of the side of arm *A*, confine the pin in the recess. One output link connects with arm *A*. Another may connect with arm *B*.



During normal operation the crank arms move as a single unit. Drive from arm B to arm A is positive in one direction, being transmitted directly from the pin on arm B to the side of arm A. In the other direction, the drive is from the pin on arm B through the leaf springs to the side of arm A. Normally, the stiffness of the springs is sufficient to prevent their bending, and arm A moves with arm B.



APPLICATION OF RELIEF DRIVE

If the mechanism driven by arm A reaches its limit of travel, arm A is unable to turn farther in the limited direction. However, the input shaft may continue turning past this point. The leaf springs, by bending, allow continued rotation of the shaft. Any mechanism connected to arm B will therefore continue to be driven by the input.

A LINKAGE NETWORK

The simplified network described here is not taken from any actual instrument. It is an imaginary network which illustrates how linkage mechanisms may be combined to solve the mathematical equations involved in a gun fire control problem.

This network computes an approximate solution of one part of a fire control problem. It computes sight angle (Vs), which is the angle that the guns must be elevated above the line of sight to allow for the drop of the projectile during its flight.

Sight angle in this problem is determined by advance range ($R2$).

Advance range is here equal to the sum of present range and the predicted change in range caused by relative motion between own ship and target. The change in range is called range prediction (Rt).

In order to compute sight angle, two quantities are used as inputs to the network:

1. Present range (R), obtained from the radar equipment.

2. Range rate (dR), the rate at which present range is changing. It is assumed that dR is available from another network, not described here.

Computing Range Prediction (Rt)

Range prediction depends upon the time of flight of the projectile and upon the range rate. For simplicity, it is assumed that time of flight (Tf) is directly proportional to present range (R), or:

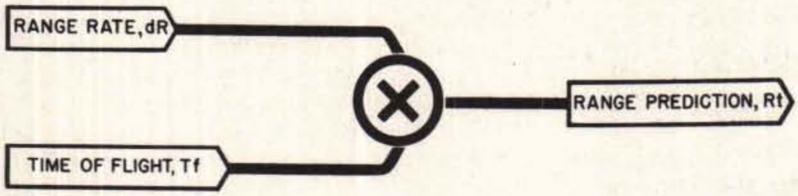
$$Tf = K \times R$$

A bell crank multiplier is used to multiply present range (R) by a constant (K) to compute Tf for any given value of R.

Range prediction (Rt) is the product of Tf and dR, or:

$$Rt = Tf \times dR$$

An XY multiplier is used to multiply Tf by dR, the quantity dR being supplied as an input to the network. The multiplier output is Rt.

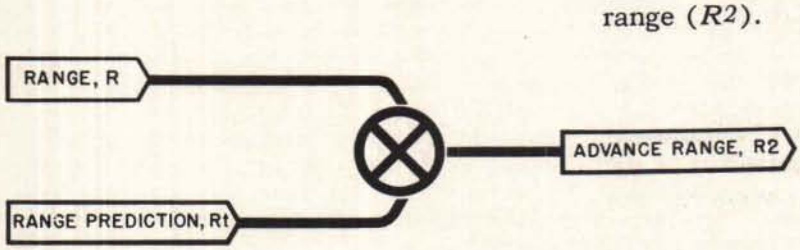


Computing Advance Range (R2)

Advance range is equal to the sum of present range and range prediction, or:

$$R2 = R + Rt$$

Both R and Rt become inputs to a linkage type differential, resulting in an output of advance range ($R2$).

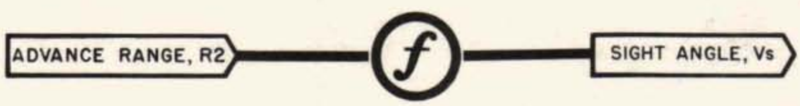


Computing Sight Angle (Vs)

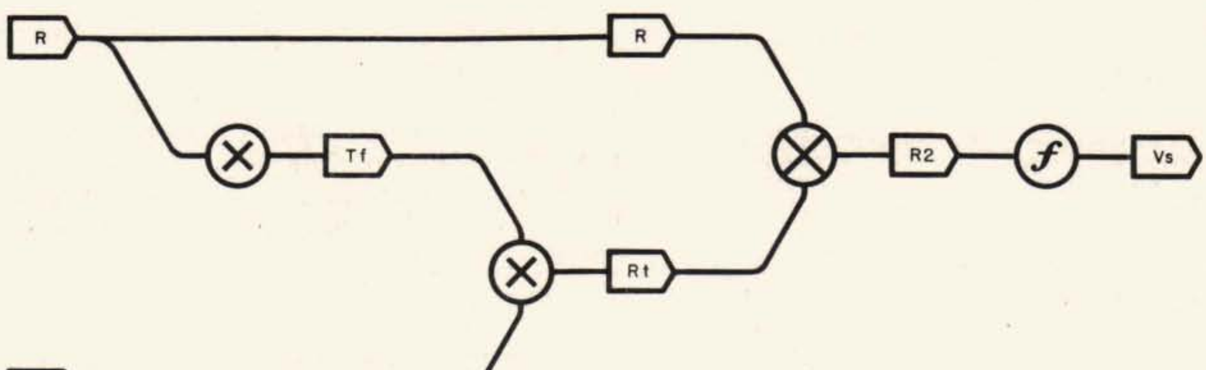
Advance range ($R2$) goes to a function mechanism which solves the equation:

$$Vs = f(R2)$$

This mechanism is designed so that its output is sight angle (Vs) corresponding to the value of advance range that is set into the mechanism.

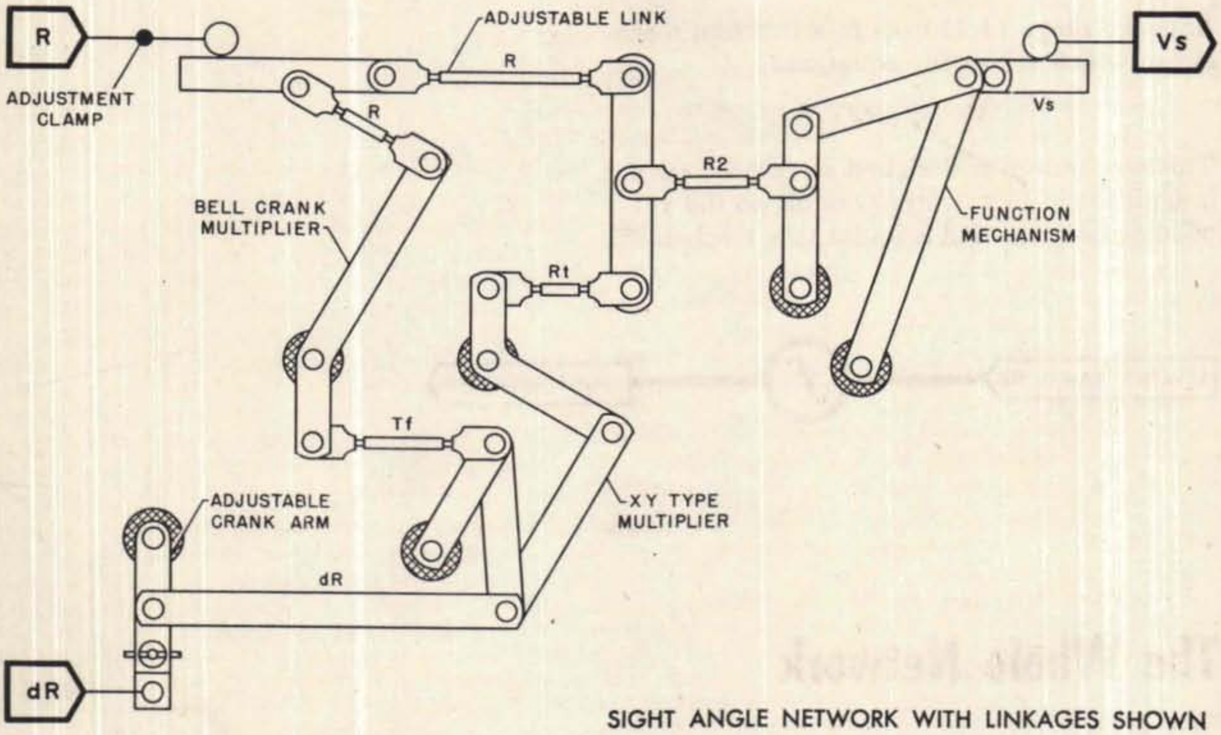


The Whole Network



A SIGHT ANGLE NETWORK

Here is what the entire network looks like, when shown schematically. Each change in the inputs to the network immediately changes the values all along the line, including the final output, sight angle.



SIGHT ANGLE NETWORK WITH LINKAGES SHOWN

Here is the complete network with the linkage mechanisms shown. The network consists of a bell crank multiplier, an *XY* multiplier, a linkage type differential, and a function mechanism.

Adjustments between the individual mechanisms are made at the points indicated.

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OP 1140 A

BASIC FIRE CONTROL MECHANISMS MAINTENANCE

A BUREAU OF ORDNANCE PUBLICATION

BASIC FIRE CONTROL MECHANISMS: MAINTENANCE

NAVY DEPARTMENT

BUREAU OF ORDNANCE

WASHINGTON 25, D. C.

22 October 1946

RESTRICTED

ORDNANCE PAMPHLET 1140A

BASIC FIRE CONTROL MECHANISMS - MAINTENANCE

1. Ordnance Pamphlet 1140A describes procedures for the diagnosis of casualties, disassembly, repair, reassembly and bench checking of basic fire control mechanisms. This book supplements OP 1140 which explains the theory of operation of these basic mechanisms.

2. This publication is a basic text and reference manual providing a source of specific information for the maintenance of basic fire control mechanisms. It is intended that the study of OP 1140A will be a prerequisite for the study of Ordnance Pamphlets on the maintenance of fire control equipment.

3. This pamphlet does not supersede any existing publication. Ordnance Pamphlet 1140, Basic Fire Control Mechanisms, should be consulted for details of operation of the mechanisms.

4. This publication is RESTRICTED, and shall be safeguarded in accordance with the security provisions of U.S. Navy Regulations, 1920, Article 76.

G. F. Hussey, Jr.

G. F. HUSSEY, JR.
Vice Admiral, U.S. Navy
Chief of the Bureau of Ordnance

Prepared For
THE BUREAU OF ORDNANCE
by the
FORD INSTRUMENT COMPANY, INC.
Long Island City, New York

TABLE OF CONTENTS

INTRODUCTION

Scope and purpose of OP 1140A

Maintenance of Basic Mechanisms, OP 1140A, was prepared to serve a dual purpose: It is both a textbook and a reference manual. Whichever way it is used, a thorough knowledge of *Basic Fire Control Mechanisms,* OP 1140, is assumed.

The novice may use OP 1140A as a primer to help him develop the skill and experience necessary for successful trouble shooting and repair of the typical basic mechanisms common to the various computing instruments. The skilled fire controlman may use OP 1140A as a guide to actual trouble shooting, disassembling, repairing, and reassembling the units for combat, where experience, skill, care, and precision finally pay off.

The various mechanisms described in OP 1140A are representative of the types of units used in the equipment. Although each unit described is actually in use in one of the major instruments in the fire control system, they are not all to be found in any single installation. Because of different features of design in the various instruments, units which are basically alike may not be identical in construction. Careful study of the typical unit, however, should lay a solid foundation for successful maintenance and repair of other units of the same type.

As a reference manual used on board ship, OP 1140A is a companion to the equipment OP's, and should be consulted only after a test analysis and unit checks as described in an equipment OP have clearly indicated that a particular basic mechanism is not functioning properly. Only mechanisms which have been disconnected from all associated units are discussed in this manual.

Removal and repair of units

If it is determined that a unit must be removed for repair, the instrument OP should always be consulted for instructions. Moreover, study of the instrument OP and OP 1140A should be supplemented by careful reference to the instrument schematic and gearing diagrams as well as the assembly drawings of the particular unit.

Beyond this, the fire controlman should always double check while the unit is still in place to make sure of the exact source of the trouble before attempting to remove any unit. This double checking is especially important because many of the units are very difficult to remove from the instruments. The actual repair job may take only a relatively short time compared with the time required to remove the unit.

As a general rule, a faulty unit or part should be replaced rather than repaired, if a replacement is available. The cause of the casualty should always be found and eliminated before the instrument is put into operation after a unit has been repaired or replaced. Otherwise the same casualty may occur again.

Estimated time on a repair job should also be carefully weighed against the possibility that the *actual time* required may be much greater. Superficial inspection may indicate only a minor repair job, yet when the unit is removed and disassembled, unforeseen repairs or replacements may be necessary. Only the responsible fire controlman can decide whether a particular repair job can be done in the time available, or whether it should be undertaken at all. Especially in combat areas, an expedient measure may be adopted instead of a more desirable repair operation. Sometimes damage which is relatively serious within a given unit may not actually affect the final computation very seriously. If the time available to make the repair is short, it may be decided to postpone the job until it is safe to secure the fire control system. In each situation, many factors must be taken into account, and all such decisions are governed by *ship's doctrine.*

Skill and precision

Modern fire control instruments are built with the fine precision traditionally associated with watchmaking. Outwardly a computer appears to be a very rugged piece of gear, and it is. But most of the working parts are machined to tolerances ranging from 0.002 to 0.0002 inch, and the surfaces of mating parts are polished to almost a mirror finish. It is obvious that skill and extreme care are required for repair operations on this equipment.

Anyone who attempts to disassemble, repair, and reassemble the basic mechanism in these instruments, especially in preparation for combat, should have a sound knowledge of basic machine shop practices. Ideally, the work should be undertaken only by a skilled fire control mechanic. In many situations, of course, experienced personnel are not available. With this in mind, OP 1140A was written so that it may be used as a guide for the less experienced. In an emergency, however, it may be advisable for an inexperienced fire controlman to call on a machinist's mate for help on machine work.

Special tools and skills

Trouble shooting and repair can often be simplified somewhat if special tools and fixtures are improvised to do particular jobs. OP 1140A gives directions for making some of the most useful of them. But because of the complexity of the instruments and the difficulty of forecasting exactly what casualties may occur, it is impossible to know just what special tools and fixtures should be at hand. The equipment of the machine shop on board ship may sometimes be used to supplement the tools in the computer tool kit.

A good deal of information about the skill and know-how developed over many years in the shops of the manufacturer is included at the end of this introduction under the heading of *Manufacturer's Practices.* This information should be very useful, but it is not intended to give specific instructions for doing any particular repair job, nor to establish any sort of doctrine.

GENERAL PLAN OF OP 1140A

The material in this manual is arranged to progress from the relatively simple to the more complex units. Since it will be used as a guide to trouble shooting and repair on board ship, the number of cross references has been held to a minimum by repeating some information in chapters where it is essential to the operations described. The subject matter is presented in five main divisions:

Part 1. Basic Tools and Operations

Part 2. Non-computing Mechanisms

Part 3. Computing Mechanisms

Part 4. Electromechanical Mechanisms

Part 5. Lubrication

It is essential that anyone using this manual be thoroughly familiar with the contents of Part 1.

Part 1. Basic Tools and Operations

Part 1 includes a presentation of the necessary tools for repairing basic mechanisms, instructions for making certain special tools and fixtures, and a detailed explanation of the essential basic repair operations on shaft assemblies. The term *shaft assembly* has been used to indicate the basic unit making up a *shaft line*. Since a large proportion of the required repairs in fire control instruments are done on shaft lines, the explanation of shaft assembly repairs is of fundamental importance.

Part 2. Non-computing Mechanisms

Part 2 is concerned with shaft lines and the various relatively simple mechanisms which are used as parts of shaft lines or in connection with them. This part of OP 1140A includes chapters on shaft lines, shaft line devices, handcranks, dial assemblies and counters, and the intermittent drive.

Part 3. Computing Mechanisms

Part 3 deals with all the basic mechanisms which actually solve the mathematical problems involved in the general fire control problem. There are chapters on the bevel-gear and jewel differentials, multipliers, component solvers and vector solvers, disk and ball integrators, the ballistic computer, and computing cams.

Part 4. Electromechanical Mechanisms

Part 4 deals with non-computing units which involve both mechanical and electrical problems. It presents chapters on wiring, push-buttons and switches, the follow-up, servo and synchro motors, synchro receivers and transmitters, time mechanisms, and the solenoid units.

Part 5. Lubrication

Lubrication is one of the most important of all maintenance procedures, of course. This final part of OP 1140A defines the proper lubricants and explains the approved methods of applying them to basic mechanisms. The information is a detailed supplement to the general instructions given in each chapter for the lubrication required in reassembling the unit.

HOW TO USE OP 1140A

OP 1140A will be much more immediately useful to the fire control mechanic who acquaints himself with the basic structure and function of the chapters in the book. A typical chapter has seven main division headings, including the chapter title, which is the name of the unit. As a rule of thumb, the unit names are ordinarily those used in OP 1140, *Basic Fire Control Mechanisms.*

Basic plan of chapters in OP 1140A

The seven main division headings of a typical chapter are as follows:

Chapter title (unit name)

Typical symptoms

Locating the cause

Dissassembling the unit

Repairing the parts

Reassembling the unit

Bench checking the unit

All these main divisions are closely related to each other, especially *Typical symptoms, Locating the cause, Disassembling the unit,* and *Repairing the parts.* For this reason, the entire chapter should be read before any disassembly or repair operation is begun, if time permits.

Chapter title (unit name)

This section introduces the fire controlman to the unit and gives him various necessary cautions. It provides a general description of the unit, the locations of the inputs and outputs, and the way the unit is mounted in the instrument.

Typical symptoms

This section gives the mechanic a bird's-eye view of the symptoms which he can check and observe without disassembling the unit. After he has correctly identified the symptom, he should turn to the proper subdivision under *Locating the cause* for help in diagnosing the trouble and prescribing treatment.

Typical symptoms consists primarily of definitions of the main symptoms of mechanical trouble, in terms of each particular unit: jamming, sticking, excessive lost motion, and slipping. These symptoms vary somewhat from unit to unit, and the electromechanical units have symptoms of electrical trouble in addition.

JAMMING means that one or more parts which should move cannot be moved by normal force, usually hand pressure. A jammed or frozen part may prevent the movement of other parts in the same unit which are not directly jammed themselves. Usually some play can be detected in a part which is held by jamming of some other part of the mechanism.

STICKING means that one or more parts move sluggishly throughout their normal travel, or resist moving past certain points where they bind or almost jam. A sticking part may jam eventually if the cause is not eliminated.

EXCESSIVE LOST MOTION means that there is too much play between sliding or otherwise mating parts which are fitted to close tolerances.

SLIPPING means that a part which should be mechanically held is free to move.

The names of the typical symptoms, usually combined with the names of particular parts, are repeated as subtitles under *Locating the cause*.

Locating the cause

Having identified the symptom, the fire controlman can use this section to help him diagnose the specific cause of the trouble in terms of pins, gears, and shafts, without unnecessary disassembly of the unit.

Under subtitles which include the names of the symptoms, there are detailed discussions of the possible causes of each one. The first sentence of each subdivision names the causes in the order in which they are discussed, and the explanation is based on the best method of checking.

Once the cause has been located, the operator will know whether the unit must be disassembled to make the repair, and he can turn to *Disassembling the unit* or *Repairing the parts,* or both.

Disassembling the unit

If the unit must be disassembled for repair, the operator will turn to this section for a reliable disassembly procedure. It is a list of steps in chronological order for the complete disassembly of the unit. Sometimes only a part of it may be used, depending on the particular repair job.

Repairing the parts

In this section, the repair man will find detailed explanations of the main repair operations prescribed in *Locating the cause.* This section does not present rigid step-by-step procedures, but offers full discussions which appeal to good judgment by suggesting alternatives and giving reasons and cautions.

Reassembling the unit

Here the mechanic will find a reliable procedure for reassembling the entire unit. It is a list of numbered steps in chronological order, introduced by an important explanation of the necessary cleaning and lubrication of all the parts as they are reassembled.

Bench checking the unit

This final section enables the fire controlman to make sure that the unit is completely ready to be reinstalled in the instrument. It presents a numbered list of essential steps and conditions.

MANUFACTURER'S PRACTICES

Here are descriptions of several maintenance operations and a number of inspection requirements which have been developed in the shops of the manufacturer of these instruments and followed successfully for many years. The descriptions offered here should be found helpful, but they are not intended to establish any sort of doctrine.

The material is presented under the following headings:

WASHING AND CLEANING OPERATIONS

There are many possible ways of washing and cleaning the basic mechanisms discussed in this OP, but some are preferable to others. Descriptions are given here of the manufacturer's methods of washing mechanical units and ball bearings, and of removing rust-preventive coatings from replacement parts.

Washing mechanical units

A suitable solvent for washing and cleaning mechanical units is Deo-base, included in the lubrication kit supplied by the manufacturer. Water-white kerosene which meets the Navy Specification 14K1 is equivalent to Deo-base. Freezene Medium Refrigerating Oil, also included in the lubrication kit, is often mixed with the solvent, 1 part in 100, to provide a protective film on metal surfaces after the solvent evaporates. This oil is a white mineral oil.

A jet spray in an especially equipped booth is often used for washing and drying operations. The booth and its accessories are designed to expel the solvent vapors so as to prevent their being inhaled by the operator; to filter dirt and chips from the solvent; and finally, to blow the excess solvent from the cleaned units with clean, *dry* compressed air.

It has been found desirable for the operator to hold the mechanisms with hooks or tongs, because the jet spray may cause skin infections if it is directed against bare hands. Chips of metal or foreign material may pierce the skin, and the solvent itself may penetrate too far into the pores.

Because of possible damage to painted surfaces, they are never subjected to the jet spray treatment.

Mechanical units may also be cleaned by the method used for washing ball bearings.

Washing ball bearings

Ball bearings and sometimes other parts of mechanical units are washed by direct immersion in the solvent. A bearing may be placed in a sieve and cleaned by agitating the sieve in the cleaning agent, or it may be dipped in the solution and turned by hand.

Dirty bearings are turned slowly to avoid possible damage to the balls and races which may be caused by spinning them too fast.

Removing rust-preventive coatings

A replacement part is immersed in a container of the solvent and allowed to stand until the heavy rust-preventive coating is completely dissolved. Then the part is rinsed in another container of fresh, clean solvent, dried thoroughly, and lubricated before it is installed.

RUNNING-IN AND FINAL FITTING OPERATIONS

Slight sticking or roughness of mating parts which are fitted to close tolerances is sometimes eliminated by lubricating and running the parts together for a short time. If running-in the parts with a lubricant does not make them operate smoothly enough, a running-in compound may be used. One compound is used for running in soft metals, and another for hardened steels.

The purpose of the running-in operation is only to remove *minor* surface imperfections on gear teeth, slide blocks, slides, and other parts which slide, roll, or in some way bear upon each other. It is essentially a polishing operation. Burrs and nicks which can be seen or felt are removed with a fine oilstone before running-in is even considered.

For running in parts made of soft metals such as aluminum, brass, bronze, and unhardened steel, 230-mesh screened rottenstone is used as the running-in agent in the compound. For running in parts made of hardened steel, pumice stone is used as the running-in agent.

A running-in compound mixed as follows has been found satisfactory:

Parts by Volume	Navy Specification
2 Petrolatum	14P1
1 DTE Light Oil	
3 { 230-mesh rottenstone for soft metals; or pumice stone for hardened steel only	

The compound is made by heating the petrolatum to about 170° Fahrenheit, adding the light oil, and then slowly adding the rottenstone or pumice stone. By vigorous stirring, the powder is smoothly and uniformly distributed throughout the compound.

The running-in compound is applied uniformly and very sparingly to the surfaces to be smoothed. The parts are then run together for a short time, slowly. Gears in particular are not run in at speeds high enough to cause the compound to be thrown off into bearings or other mechanisms. After the running-in operation is completed, every trace of the compound is washed from the unit, because if it is not completely removed, it may cause excessive and uneven wear or possible damage to some of the parts, *especially the bearings.* Finally, the unit is completely lubricated.

CEMENTING OPERATIONS

Two cementing procedures used by the manufacturer are described here: cementing *cork to metal,* and cementing *rubber* or *neoprene* gaskets.

Cementing cork to metal

Cementing cork to metal involves cleaning the surfaces of the cork and the metal, applying the adhesive to both parts, pressing them together at the right time, and finally, clamping the parts and baking them. The materials used are adhesive and cleaning agents.

The adhesive is a pure orange shellac, an 8-pound cut of the type included in the lubrication kit supplied by the manufacturer. It meets Federal Specification TT-V-91a, Type 11 Orange, Grade A. Thinned adhesive is made by diluting one volume of the shellac with two to three volumes of denatured alcohol which meets Federal Specification TT-V-91.

The cleaning agents are trichlorethylene, lacquer thinner, or gasoline. The trichlorethylene meets Navy Specification S1T3; the lacquer thinner meets Federal Specification TT-T-266; the gasoline is a commercial white gasoline which contains *no* tetraethyl lead.

The *metal* surface is cleaned with trichlorethylene, lacquer thinner, or gasoline. Then it is air-dried and wiped clean with a cloth dampened with alcohol. Either of two methods is used to clean the *cork* surface: It may be wiped with a cloth dampened with lacquer thinner or gasoline, and then allowed to dry thoroughly; or if the surface is dry, it may be roughened with a fine file and the dust and particles air-blown away.

A coat of thinned adhesive is applied to both the cork and the metal surfaces, and they are air-dried for fifteen minutes.

A coat of pure orange shellac is then applied to the cork. The cork is immediately pressed firmly and evenly against the prepared surface of the metal. Considerable care is required to obtain a good bond, free of air bubbles.

In preparation for baking, the cork is covered with parchment paper to prevent its sticking to the clamp. The cemented parts are then clamped together and baked at 275° Fahrenheit for four hours or at 300° for three hours.

Cementing gaskets

Cementing a rubber or neoprene gasket to a metal cover is an operation similar to cementing cork to metal, but it is simpler because fewer steps and materials are required.

The adhesive used by the manufacturer for *neoprene* gaskets is No. 1 Fairprene cement. It becomes tacky in 30 minutes to one hour after it is applied. If it becomes too thick, it is usually thinned with trichlorethylene.

The adhesive used for *rubber* gaskets is No. 1201 Red Glyptal. It becomes tacky in 5 to 15 minutes after application. If necessary, it is thinned with No. 1500 GE thinner. Both materials are included in the lubrication kit supplied by the manufacturer.

Before the scarfed ends of a gasket are cemented together, they are cleaned with trichlorethylene. When they are dry, a coat of adhesive is applied to each scarfed end and they are then air-dried until the adhesive becomes quite tacky. Finally, the ends are pressed firmly and evenly together.

When a neoprene or rubber gasket is cemented to a metal cover, a coat of the proper adhesive is applied to both the gasket and the groove. The adhesive is air-dried until it becomes tacky, usually 30 minutes to one hour. Then the gasket is pressed into the groove very carefully to keep it from twisting. Any excess adhesive is wiped away with a cloth dampened with solvent. Finally, the cover is bolted to the instrument case so that the gasket is held firmly in place.

ASSEMBLY AND INSPECTION REQUIREMENTS

It is the accepted practice in the shops of the manufacturer to consult the assembly drawings of every particular unit for special information applying to that unit. Several general practices are followed, however, unless the assembly drawings specify a variation.

General tolerances and practices

Clearance between unrelated moving parts is not less than 0.008 inch.

Cotter pins are locked.

Shims are never used unless an assembly drawing specifies them.

Dowel holes are drilled when the mating parts are in their exact relative positions. The holes are perpendicular to the joining surfaces, and they are fitted so as to allow the parts to be separated and rejoined.

In *screw-driven mechanisms,* the screw turns freely but the total end play of the part moved and the screw shaft does not exceed 0.0015 inch.

The lost motion of a cam on a center pivot does not exceed 0.0005 inch.

The lost motion between a cam and a carriage in the direction of the carriage travel does not exceed 0.001 inch.

An *eccentric adjustment stud* is staked to hold it in position after an adjustment has been made. In staking a stud, a center-punch mark is made in the metal part where the stud is mounted, 1/32 inch from the edge of the stud and in line with the center of the slot. The effect of staking is to force a small amount of metal into the stud slot.

Flat-head screws are staked in the same way as eccentric studs except where the head is tightened against a hardened steel surface or a plate less than 3/32 inch thick.

Steel cap screws are lubricated with W. S. 511 grease before they are screwed into aluminum or steel. This grease is included in the lubrication kit.

Aluminum screws used in aluminum parts are lubricated with the anti-seize compound which is included in the lubrication kit. The compound is applied only to male threads, and it is carefully kept away from neoprene, rubber, or other plastic gaskets which it may damage by chemical action.

Shaft assemblies

A *spacer* is considered satisfactory when it properly fills the space where it is used. An additional, or extra spacer is never used. If a spacer is too thin, it is replaced; if it is too thick, it is filed down to the proper size.

A *taper pin* is set with the large end 0.005 to 0.01 inch below the surface of the hub, to provide room for staking. The small end is set within 0.01 inch above or below the surface of the hub. Where the hub must be smooth so that another part may turn on it, as in a friction assembly, for example, both ends of the pin must be below the surface. Every taper pin is driven in tightly and staked.

Adjustable or split hubs: A film of Freezene medium refrigerating oil is applied to the shaft and hub before the clamp is mounted. Before the screw is tightened, the clamp fits snugly on the hub and the hub turns freely on the shaft. After the screw is tightened, the clamp holds the hub firmly on the shaft without closing completely.

Computer mechanism gearing

End play, lost motion, and run-out of shafts and gears are kept within the following limits, measured with a dial indicator:

End play of shafts with straight-tooth spur gears: 0.0005 to 0.003 inch.

End play of shafts having one or more bevel, worm, or helical gears: 0.001 inch maximum.

Lost motion at gear meshes of spur, bevel, worm, and helical gears averages no more than 0.001 inch, and does not exceed 0.002 inch at any one mesh.

Run-out is measured by means of a dial indicator mounted with the point against the part in question. The limits apply to the total variation of indicator readings during one revolution.

A spur gear does not wobble more than 0.002 inch.

Bevel-gear eccentricity and wobble does not exceed 0.001 inch. This measurement is made with a dial indicator held perpendicular against the heel of the gear, near the root line of the teeth.

Synchro-receiver shaft assemblies run freely without apparent end play, lost motion, or run-out.

Component solvers

The travel of the racks is limited only by the cam groove or the lead screws.

Nothing interferes with the turning of the vector gear through 360°, regardless of the position of the pivot, except the stop pins, or, in some screw-type component solvers, the screw-input shaft hangers.

The center of the pivot passes through the axis of vector gear rotation within $\pm$ 0.001 inch.

Rack slots are at right angles to each other within 0.002 inch total variation of indicator readings throughout the travel of each rack.

Disk integrators

Balls, disks, and rollers are free from dents, nicks, pits, scratches, soft spots, and all other surface imperfections.

The force necessary to move the carriage through its full travel does not exceed 1/2 ounce when the disk is horizontal and the roller is raised.

The disk is firmly clamped to the gear.

The clearance between the carriage balls and guide rollers does not exceed 0.0005 inch.

The side play of the carriage within the rails does not exceed 0.001 inch.

The clearance between the gear and the ball-bearing ring on the bottom of the gear does not exceed 0.001 inch.

The disks run in a plane parallel to the axis of the roller within 0.005 inch. This measurement is made with a dial indicator against one of the roller bearings. When the disk is turned and the carriage moved through its entire travel, the total indicator readings do not vary more than 0.010 inch.

Cam type multipliers

The travel of the parts driven by the cam is limited only by the cam groove.

The cam is concentric with its pivot within 0.001 inch, measured on the outside diameter.

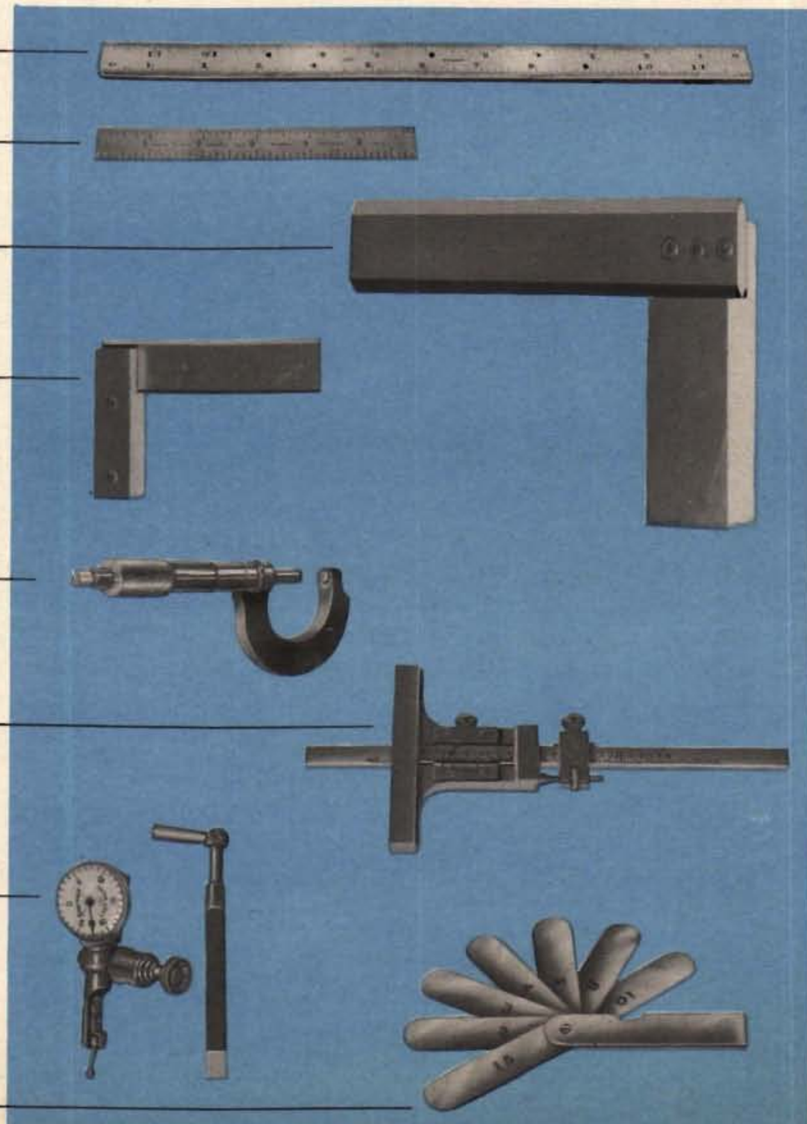
Screw type multipliers

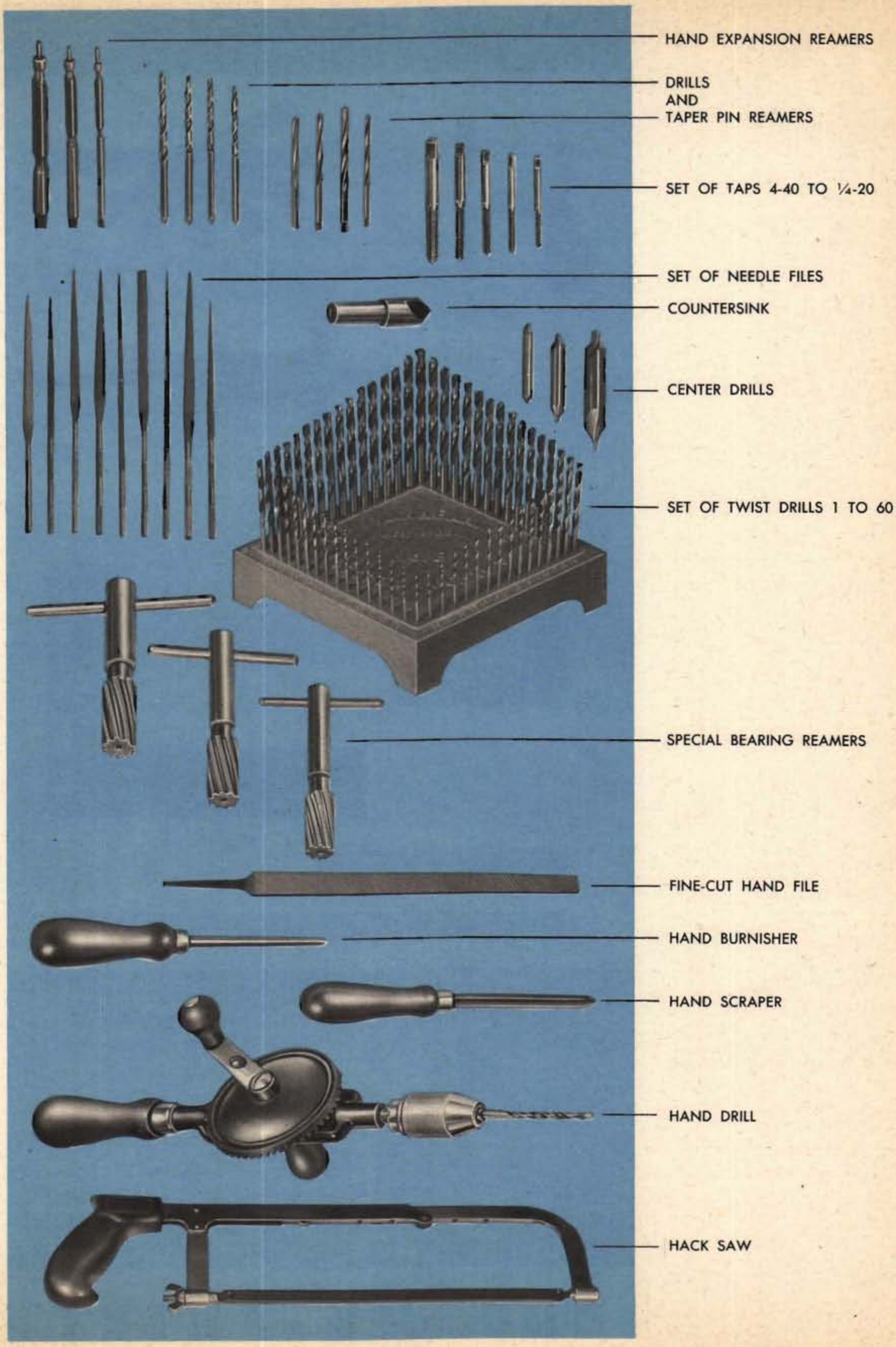
When the traveling blocks are displaced one inch from the fixed pivot, the lost motion between the input and output racks does not exceed 0.003 inch.

TOOLS and MATERIALS

Every repair man should have on hand the measuring instruments, hand tools, and bench equipment pictured on the following pages. In this OP, the explanations of instrument maintenance are based on the assumption that this equipment is available to the repair man and that he understands how to use it.

Not all this equipment will be required for any one instrument repair job, but the chapter on basic repair operations will show that many of them are used even on a simple job.




HAND EXPANSION REAMERS
DRILLS
AND
TAPER PIN REAMERS
SET OF TAPS 4-40 TO ¼-20
SET OF NEEDLE FILES
COUNTERSINK
CENTER DRILLS
SET OF TWIST DRILLS 1 TO 60
SPECIAL BEARING REAMERS
FINE-CUT HAND FILE
HAND BURNISHER
HAND SCRAPER
HAND DRILL
HACK SAW

ELECTRICIAN'S PLIERS

ROUND NOSE PLIERS

LONG NOSE PLIERS

ELECTRIC HAND DRILL

PIN PUNCHES

TAP WRENCH

CENTER PUNCH #8

TAPER PIN PUNCHES

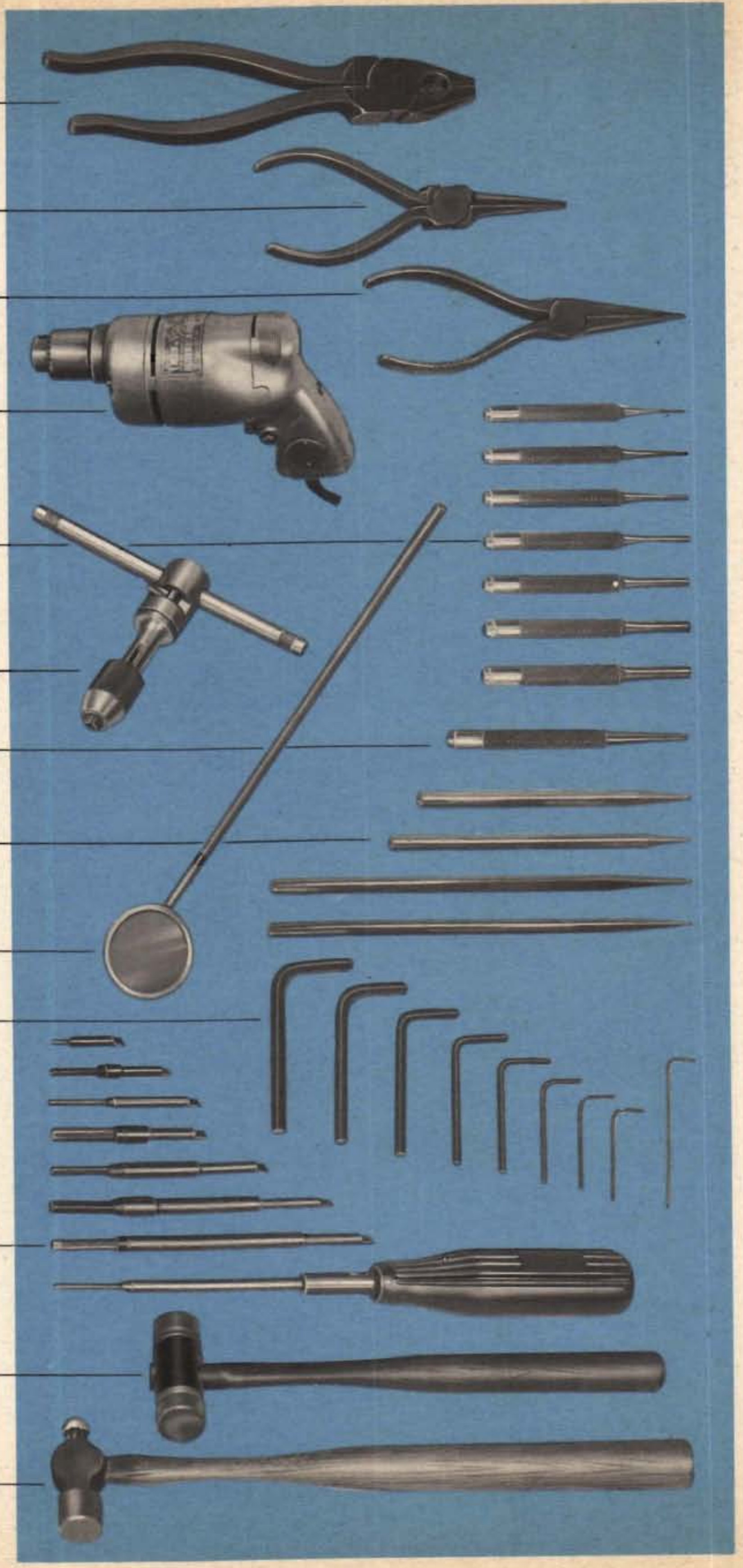
DENTAL MIRROR

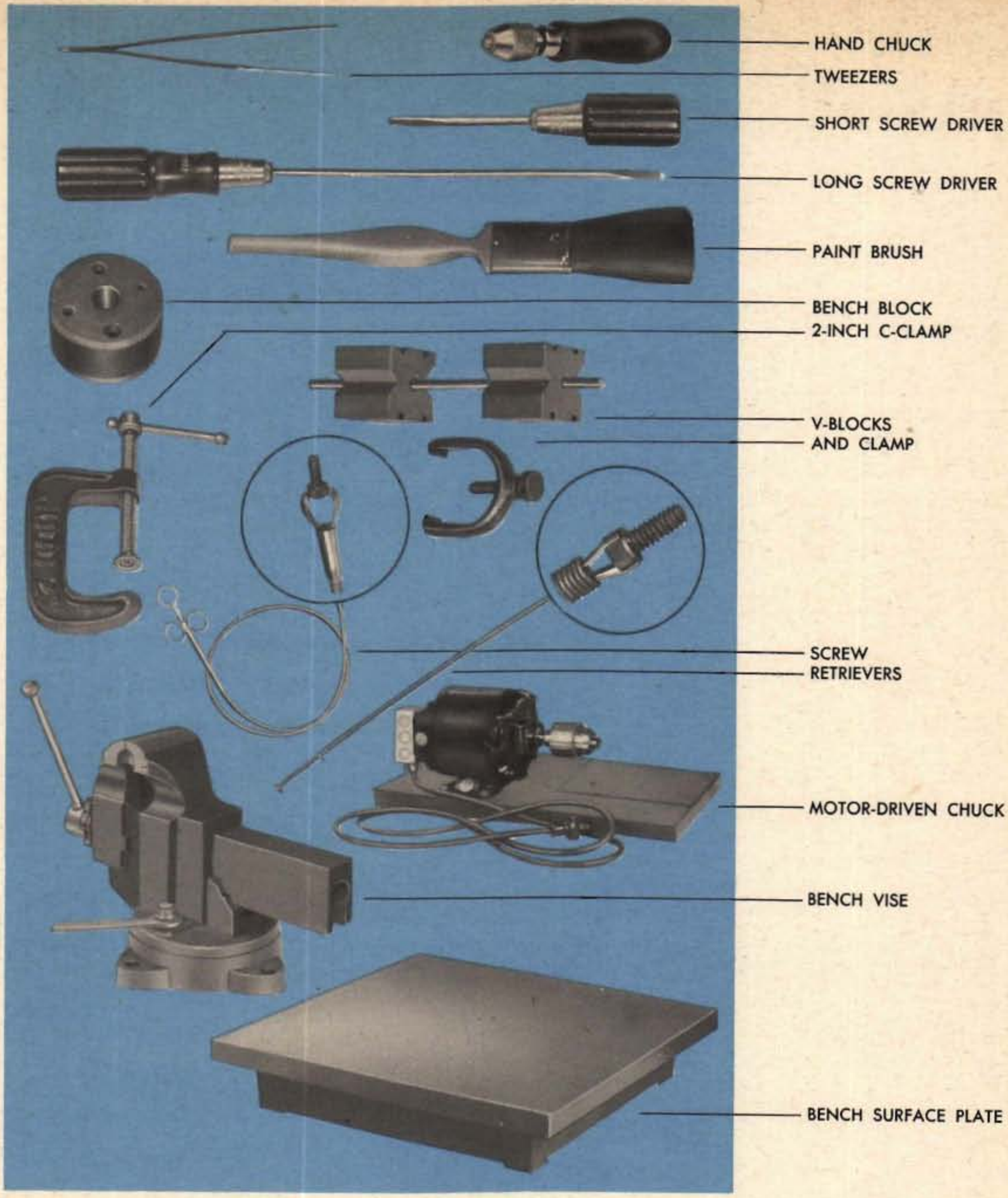
SOCKET-HEAD SCREW WRENCHES

SOCKET-HEAD SCREW EXTENSION BITS AND HANDLE

PLASTIC HAMMER

BALL-PEEN HAMMER





Materials

In addition to this equipment, the following materials are required for instrument repair work:

A suitable cleaning solvent.
A light machine oil.
Grease conforming to Army and Navy Aeronautical Spec. AN-G-3.
Crocus cloth, very fine sandpaper, and an oilstone.
An assortment of set screws, taper pins, soft iron wire, scrap metal rods, bakelite, etc.
Some cheesecloth and a quantity of lint-free rags.

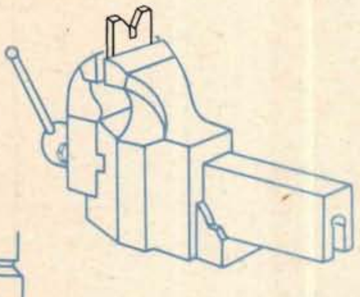
MAKING SPECIAL TOOLS AND FIXTURES

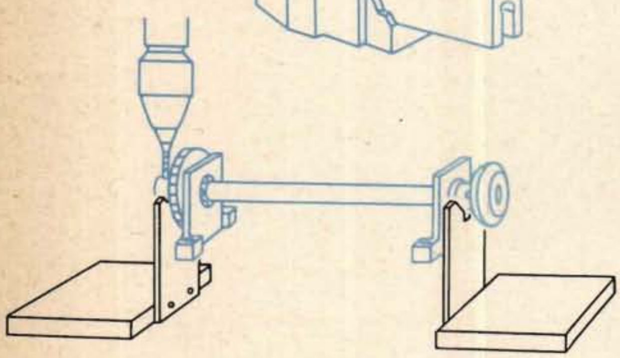
A few easily-made tools and fixtures will simplify all shaft-assembly repair in an instrument, and making them will give the trouble shooter a practical introduction to the tools and materials in his kit. Instructions follow for making these tools and fixtures:

- Pinning supports
- Back-up tools
  - A back-up bar
  - A hook support
- A bearing punch
- A support for seating and removing bearings
- A spacer filing fixture
- Pin removers
- An inside knurling tool
- Snap ring tools
- A socket-head screw remover

The instructions given here for making these tools are meant to be general, so that they can be applied to different situations. All dimensions should be considered only approximate, and if a specified material is not available, a substitute will serve the purpose.

SIMPLE PINNING SUPPORT



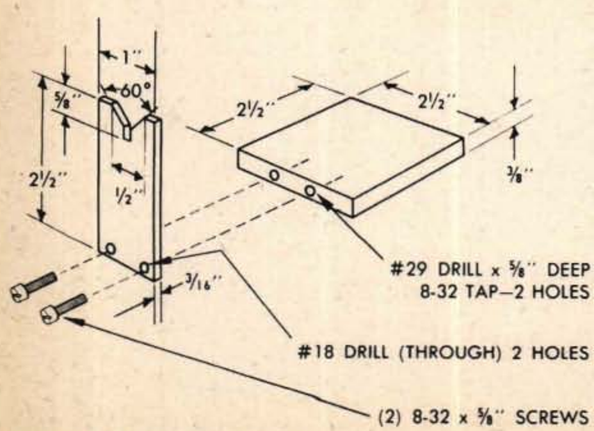


PINNING STANDS IN USE

Pinning supports

A simple pinning support to be held in a vise can be made of a flat strip of metal with a 60° notch cut in one end. This type of support is suitable for small repair jobs involving only a few shaft assemblies.

It is more convenient to have a *pair of pinning stands* as supports on the bench for shafts when they are checked for run-out or straightened, and for gears when they are drilled and pinned. For drilling and pinning operations, one of the stands is always placed directly under the hole or part to be worked on.



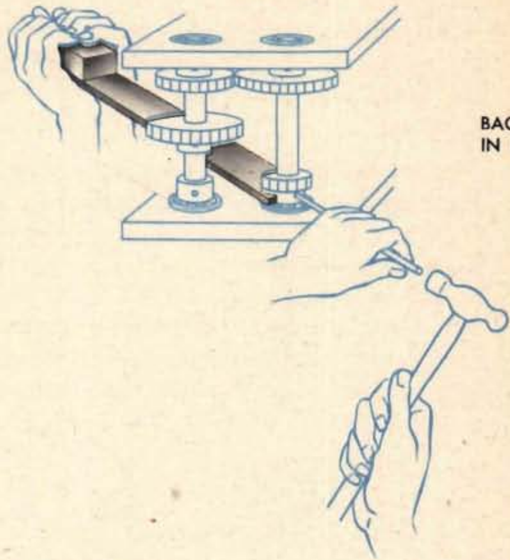
THE PARTS OF A PINNING STAND

MATERIALS: For the uprights, two strips of brass 2½" by 1" by 3/16" are needed, and for the bases, two steel blocks 2½" by 2½" by 3/8". Four screws 8-32 by 5/8" fasten the uprights to the bases.

Use a hack saw to cut a notch in the top of each upright to receive the parts when the stands are in use. First cut a V to form an angle of 60 degrees. Then cut a 1/8" slot in the bottom of the V, 5/8" deep measured from the top of the upright.

Back-up tools

Back-up tools are needed to support collars and hubs for pinning whenever parts must be pinned inside a large gearing group. A back-up bar is used when the part to be pinned can be reached from both sides, and a hook support when it can be reached from only one side. Two men are required for pinning when back-up tools are used.

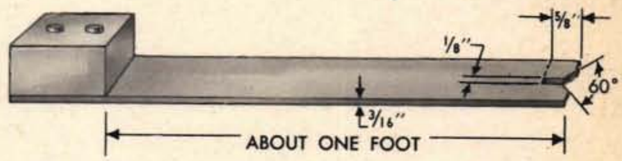


BACK-UP BAR IN USE

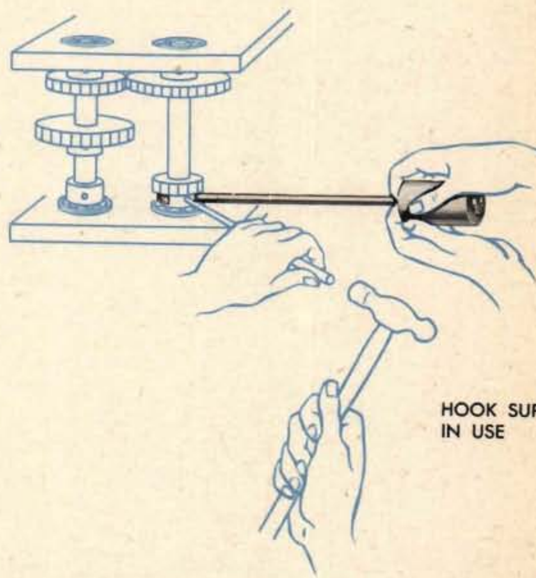
BACK-UP BAR

MATERIALS: The main element is a steel bar about 12″ long, 1″ wide, and 3/16″ thick. A steel or lead weight is attached to one end of this bar to absorb shock.

Make a notch in one end of the bar as described for the pinning-stand uprights. The weight may be screwed, riveted, or cast onto the other end of the bar.



BACK-UP BAR



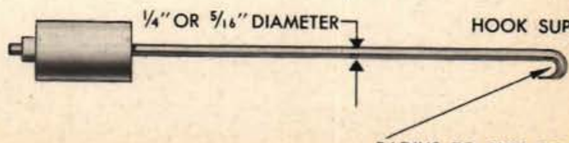
HOOK SUPPORT IN USE

HOOK SUPPORT

MATERIALS: The main element is a 1/4″ or 5/16″ steel rod at least 12″ long. A metal weight is attached to one end to absorb shock.

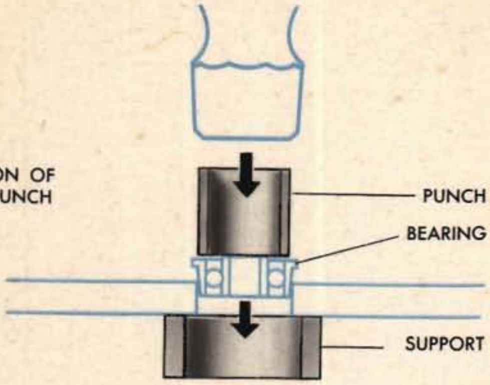
Forge a smooth hook on one end of the rod to fit the collars and gears to be held. During the forging operation, reduce the diameter of the rod at the hook end to about 3/16″ to enable the hook to enter narrow spaces easily. Then file the tip flat on the outside.

Fasten the weight to the other end of the rod as described for the back-up bar.

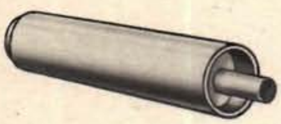


HOOK SUPPORT

CROSS-SECTION OF A BEARING PUNCH IN USE



A PILOTED PUNCH

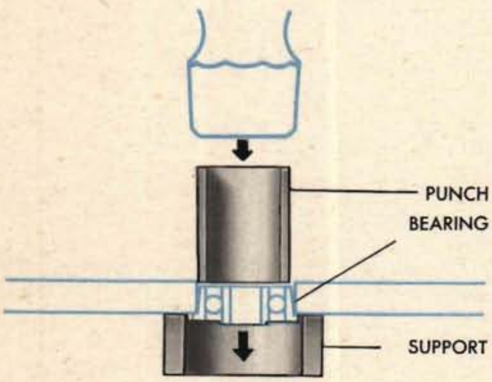


Bearing punch

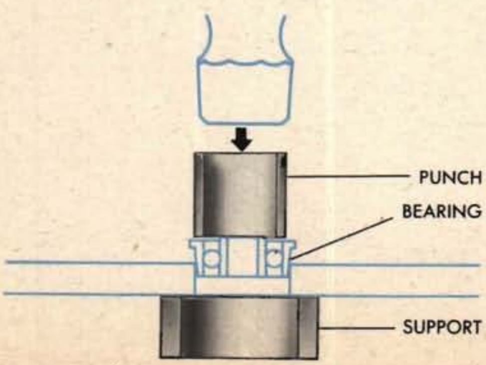
A bearing punch is needed to distribute and equalize the force of the hammer blows when bearings are removed or seated. For most repair work, all that is needed for a punch is a short, square-cut length of tubing about 0.005 inch smaller in outside diameter than the bearing hole. This tube must fit *inside the bearing hole and on the outer race* of the bearing.

For production work, a punch with a pilot to center it will save time. The pilot fits through the shaft hole, and the outer lip on the punch fits inside the bearing hole and on the outer bearing-race. A punch of this type can be turned on a lathe from a solid steel bar.

REMOVING A BEARING



SEATING A BEARING



Support for seating and removing bearings

A support must be used under a hanger or a plate to prevent its being bent when a bearing is removed or seated. All that is needed for a support is a square-cut piece of tubing large enough in diameter to fit around outside the bearing, and long enough to support the part conveniently on the bench.

Spacer filing fixture

In a shaft assembly, spacers are washers, or metal tubes of different lengths and diameters, which are fitted between the parts to hold them in their proper positions. In thickness or length, they vary from a few thousandths of an inch to several inches. The correct spacer length is determined by measuring the distance between the parts, or by the trial-and-error method of filing the spacer until it exactly fits its place in the assembly.

In all shaft-assembly repair work, spacers must be filed to the exact length, with the ends parallel and square with the bore. A spacer may be held in the hand and filed, but a spacer filing fixture simplifies this important filing operation.

MATERIALS: For the base, a steel plate 6″ by 2″ by ⅜″ is needed, and for the posts, three steel rods 3/16″, 1/4″, and 5/16″ in diameter and 1½″ long.

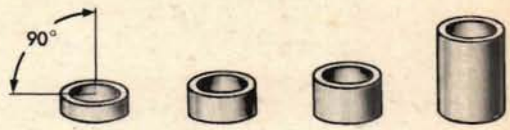
Drill three holes through the center of the base to receive the posts and ream them for a drive-fit.

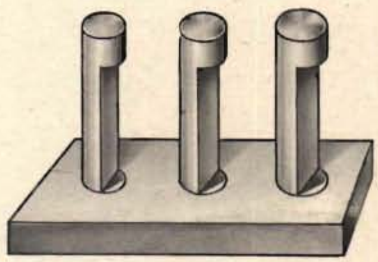
File each post on one side until there is a broad, flat surface to within ⅜″ of each end. To assemble the fixture, carefully drive the finished posts into the holes in the base.

TO FILE A SPACER, slide it over the post of the proper diameter. Use a fine-cut hand file, with smooth edges which will not file the post. It is important to keep the file parallel to the base, so that the file turns the spacer on the post and files the end square. Guide the smooth edge of the file along the flat side of the post. Using light but steady pressure, file the end of the spacer with long, even strokes.

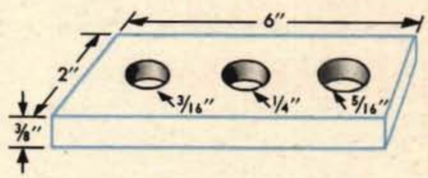
Before trying a filed spacer on the assembly, carefully remove all filing burrs and metal particles. Finally, measure it with a micrometer to be sure that the ends are parallel.

SPACER ENDS MUST BE PARALLEL AND SQUARE

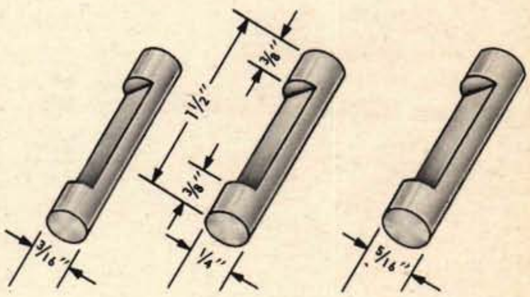




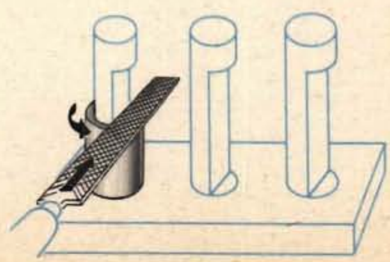
COMPLETED FILING FIXTURE



BASE

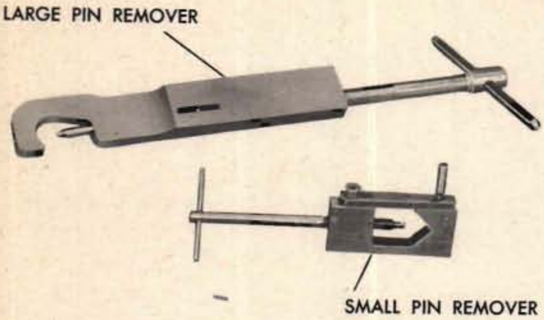


POSTS



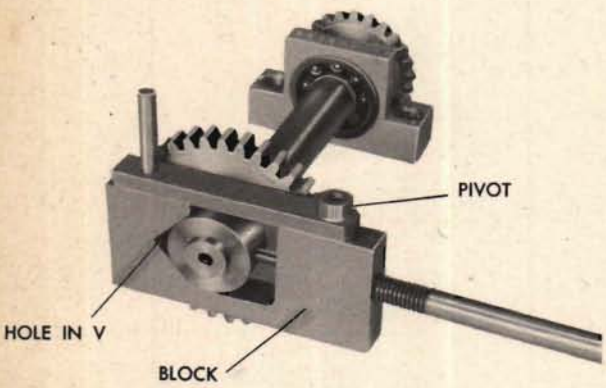
FILING A SPACER

Pin removers

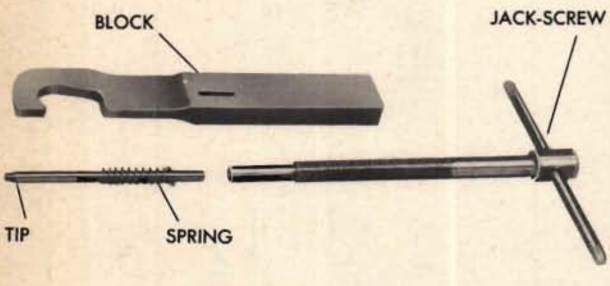


A pin remover is a special tool which may be used in place of the punch, hammer, and back-up tool combination. It greatly lessens the danger of bending a shaft and permits one-man operation.

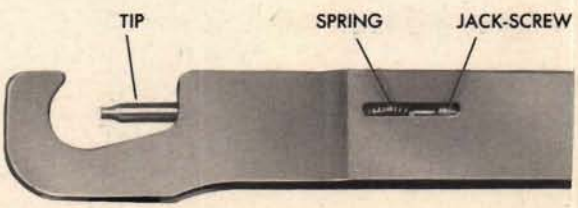
The smaller of the tools illustrated is made from scrap tool steel. The block measures 2″ by 7/8″ by 1/4″. A hole or slot at the bottom of the V allows the pin to pass through. The pivoted bar over the jaw takes up any strain on the open side. The jack-screw, of 3/16″ diameter stock, is turned down at one end to fit the taper pins generally used. It is helpful to cup the end. A simple handle affords leverage.



The larger tool is more difficult to make, but it has several advantages over the smaller one. The punch end, or tip, does not turn with the jack-screw. This prevents "walking" away from the taper pin. With this tool it is possible to use several sizes of tips, including one for staking. The block for the tool illustrated measured 6″ by 1″ by 7/16″ before machining. The jack-screw is machined from a 6″ length of 1/2″ diameter rod. The tip is shaped from a length of 1/8″ rod.

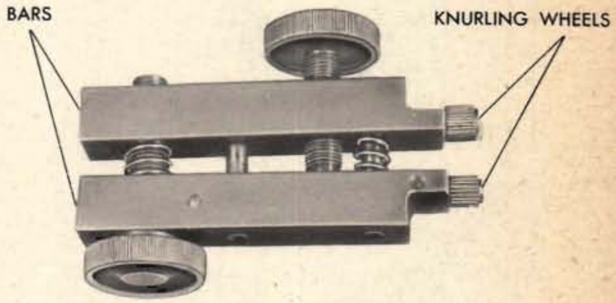


It is preferable to harden all the parts of these tools. If tool steel of the proper size and shape is not available, however, almost any steel will serve for all parts except the tip.

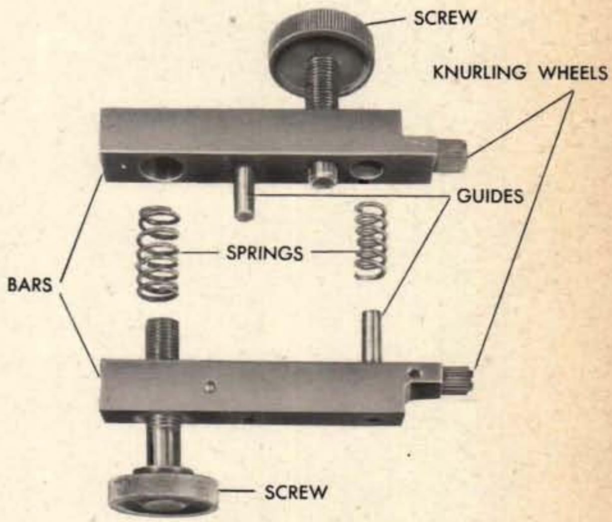


An inside knurling tool

Except in emergencies, it is not advisable to reduce the diameter of a bearing hole in a hanger or plate. When an emergency arises, however, knurling is probably the best method. It is a means of making a temporary tight fit without a great deal of machining or preparation of intricate shims.

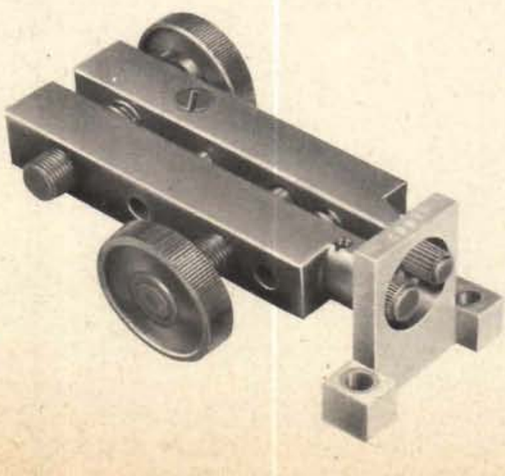


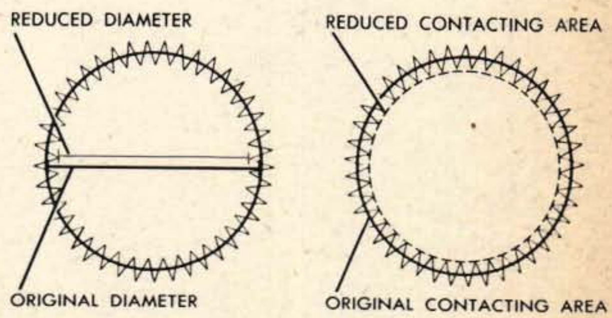
The tool illustrated cannot be bought. It is simply a mechanic's idea of a handy gadget to have in the tool drawer.



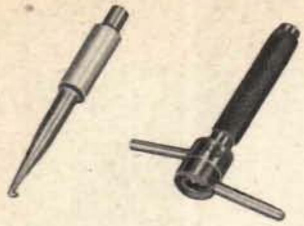
An inside knurling tool is somewhat like a parallel clamp except that the action of the bars is to spread rather than close. A knurling wheel on a stud is mounted at the working end of each bar. These wheels must be free to turn on the studs. Both the studs and the wheels are made from tool steel and hardened.

By forming a series of teeth on the inside surface of the hole, the effective diameter is reduced, but at the same time the contacting area is greatly decreased.



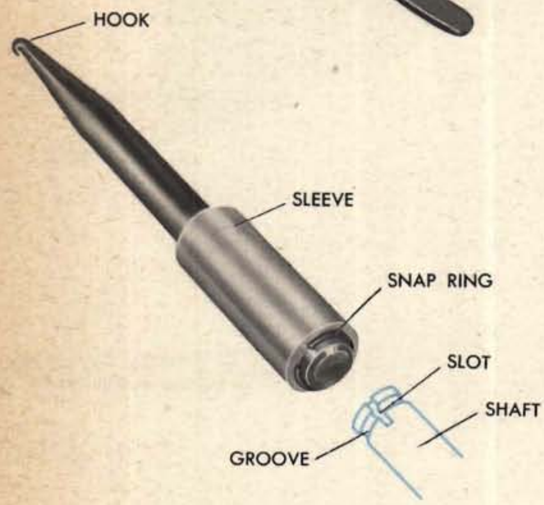


Snap ring tools



The tools shown here are designed to facilitate the installation or removal of the various types of snap rings.

With the proper tool, the handling of snap rings is quite simple. Without the tool, it is often difficult and usually results in damaged shafts, scratched parts, lost rings, and sometimes personal injury.



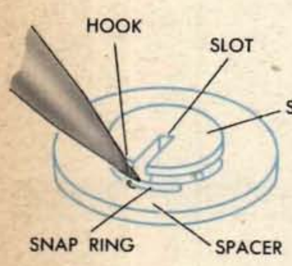
Several types of snap rings have been developed to meet the particular requirements of various intricate mechanisms. In repairing the mechanisms described in this OP, three types of snap rings will be encountered:

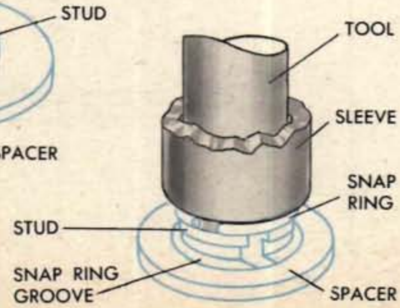
The circular cross-section snap ring, with a small gap.

The square cross-section snap ring, with a large gap.

The square or rectangular cross-section snap ring, fitted with eyes in flanges to accommodate a special installation tool.

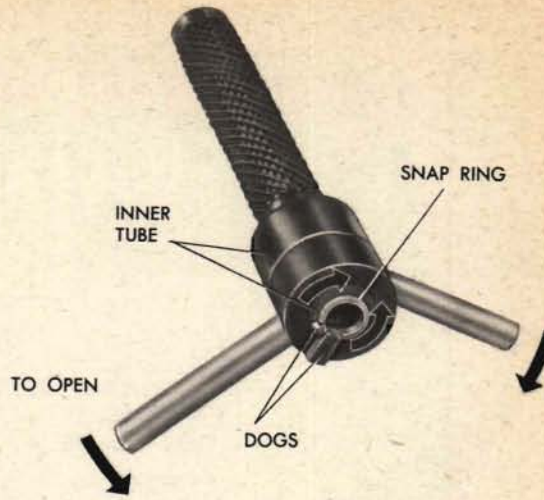
REMOVING AND INSTALLING A SNAP RING WITH A CIRCULAR CROSS-SECTION AND A SMALL GAP





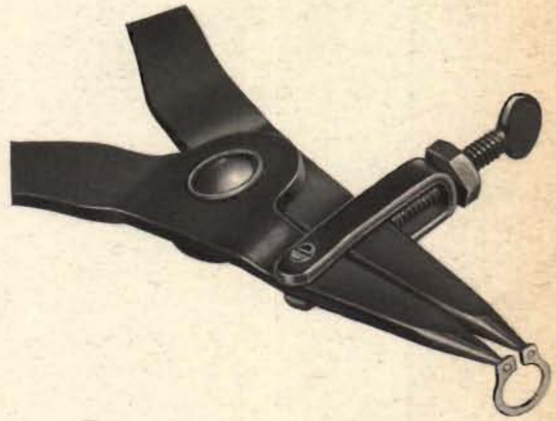
To remove the ring, slip the hooked end of the tool under the ring at the recess made by the slot in the shaft. Pull the ring off. To install a ring, slide the ring on the tool, following with the sleeve. Set the rod against the shaft and transfer the ring to the shaft by means of the sleeve.

REMOVING AND INSTALLING A SNAP RING WITH A SQUARE CROSS-SECTION AND A LARGE GAP



To remove the ring, close the dogs by turning the handle of the inner tube counterclockwise. This positions the handles at about ninety degrees. Slip the tool over the shaft extension with the dogs inside the ring gap. Squeeze the handles to force the dogs apart and open the gap in the ring. This tool was designed for removing rings, but with careful handling it can also be used for installing them.

REMOVING AND INSTALLING THE SPECIAL TYPE OF SNAP RING

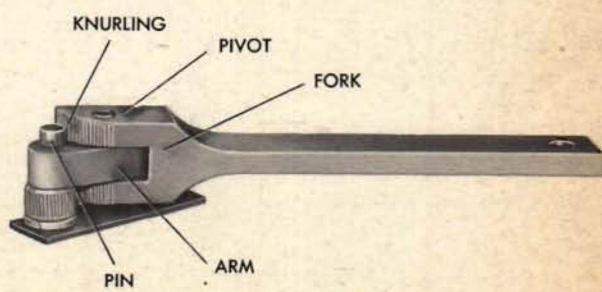


This is a commercial tool, supplied by the manufacturer of these rings. The method of using this tool is obvious.

Socket-head screw remover

This is a special tool for removing socket-head screws in which the hexagon socket has been mutilated.

The principle is the same as that of the tool for removing studs. It functions like an offset pipe wrench, adapted to a socket-head screw.



An arm with a pin through it pivots in a fork. The fork is knurled at the contacting surfaces. This type of tool is made from tool steel and hardened.

BASIC REPAIR OPERATIONS

SHAFT ASSEMBLIES

Generally in fire control instruments, quantities are transmitted by shafts and gears. Several kinds of shaft assemblies, which may be connected in many ways, are used to make up instrument shafting and gearing. For this reason, a basic knowledge of shaft assemblies is required for maintenance of these instruments.

This chapter is mainly an explanation of basic repair operations on shaft assemblies considered as mechanical units. Sometimes a shaft assembly must be treated not as an entirely independent unit, but in its connections with other units in an instrument. In general, however, basic repair operations are understood to include all those operations which may be necessary for the repair of any shaft assembly taken as a unit.

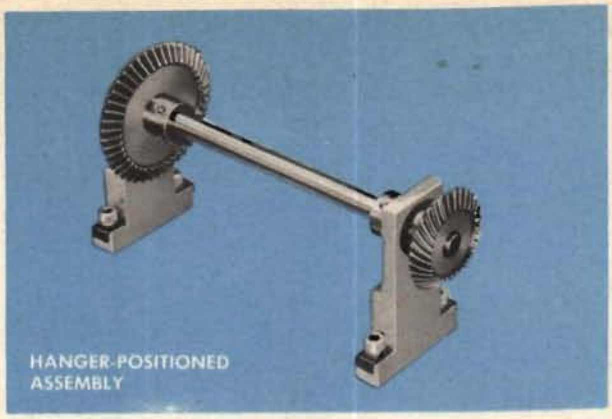
Some familiarity with the tools and materials described in the previous chapter is assumed.

Maintaining proper operation of a fire control instrument often requires moving a gear, installing a longer spacer, filing a collar or spacer, or repositioning an entire shaft assembly by moving the hangers. Maintenance may also require replacing a shaft or gear, or even rebuilding an entire assembly.

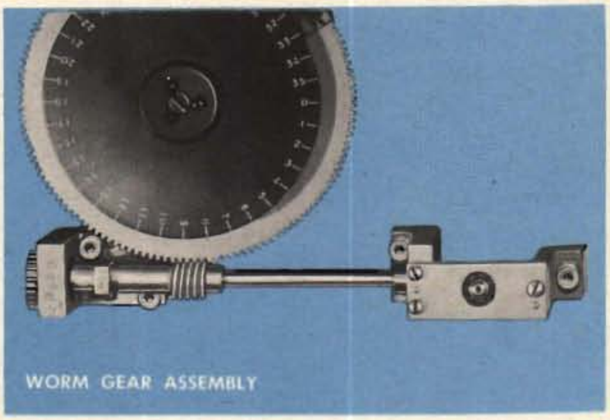
All repair of shaft assemblies is carried out in seven main steps:

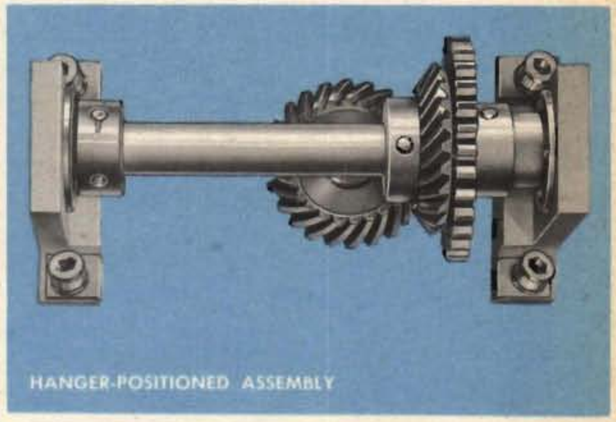
1 Removal and disassembly
2 Preparing the parts
3 Fitting the parts
4 Positioning the assembly on a plate
5 Pinning the parts
6 Bench checking the assembly
7 Final mounting of the assembly

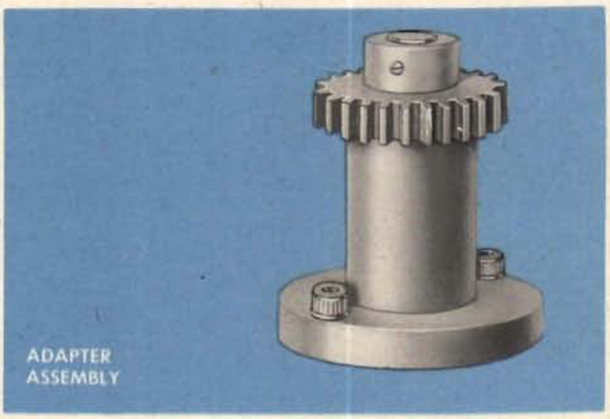
The steps of this procedure must be followed just as carefully when only one part is repositioned or replaced as when an entire shaft assembly is rebuilt.

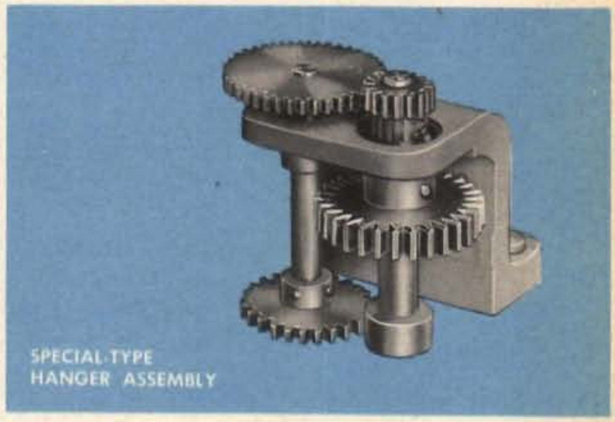

HANGER-POSITIONED ASSEMBLY

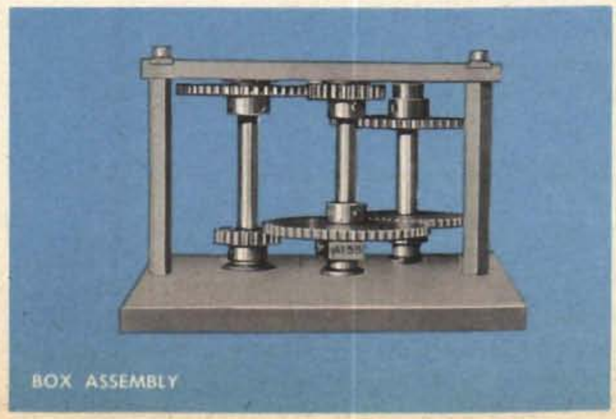

HANGER-POSITIONED ASSEMBLY WITH A CLAMP GEAR

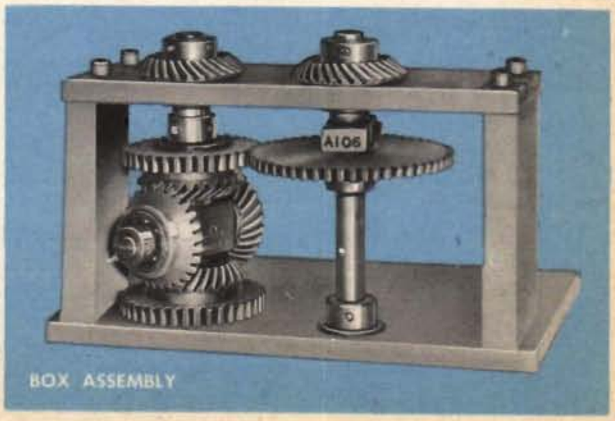

WORM GEAR ASSEMBLY


HANGER-POSITIONED ASSEMBLY


ADAPTER ASSEMBLY


SPECIAL-TYPE HANGER ASSEMBLY

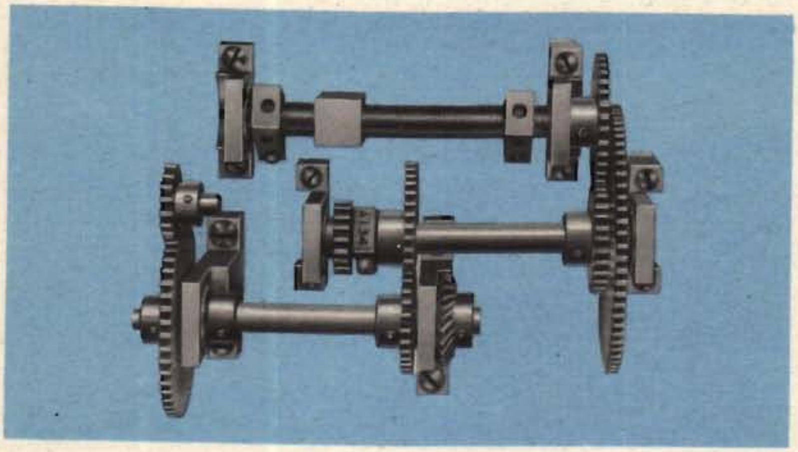

BOX ASSEMBLY



BOX ASSEMBLY

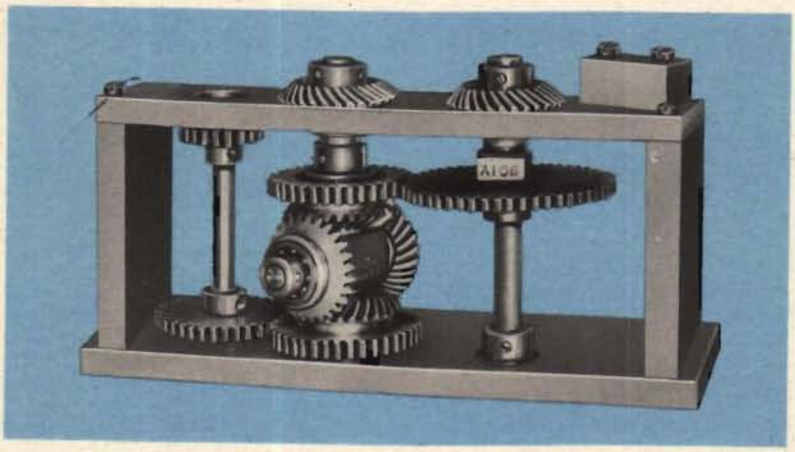
Removal and disassembly

Shaft assemblies are usually mounted either on plates or between the plates of a box assembly.



SHAFT ASSEMBLIES ON A PLATE

Those mounted on plates are positioned by screw-fastened hangers.



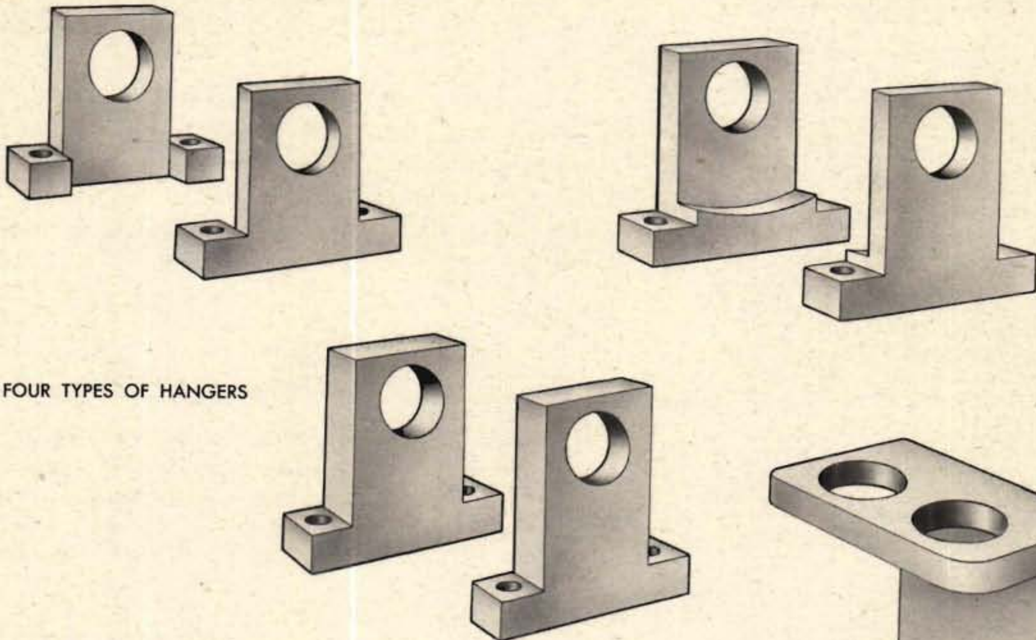
SHAFT ASSEMBLIES BETWEEN PLATES

Those mounted between plates are positioned by the plates themselves, which are secured by screws but held in position by dowels.

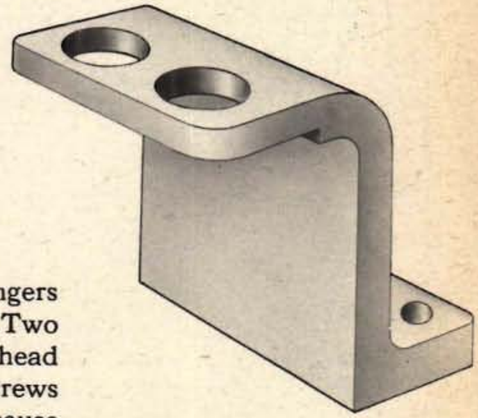
Some plates are supported by posts to which they are fastened by screws.

Shaft assemblies are precision mechanisms, made up of light parts machined and fitted to close tolerances. All removal and disassembly operations must be carried out with great care in order to avoid damage to any of the parts. Always use the lightest tools and the least physical force that will do the job.

Removing hanger-positioned assemblies



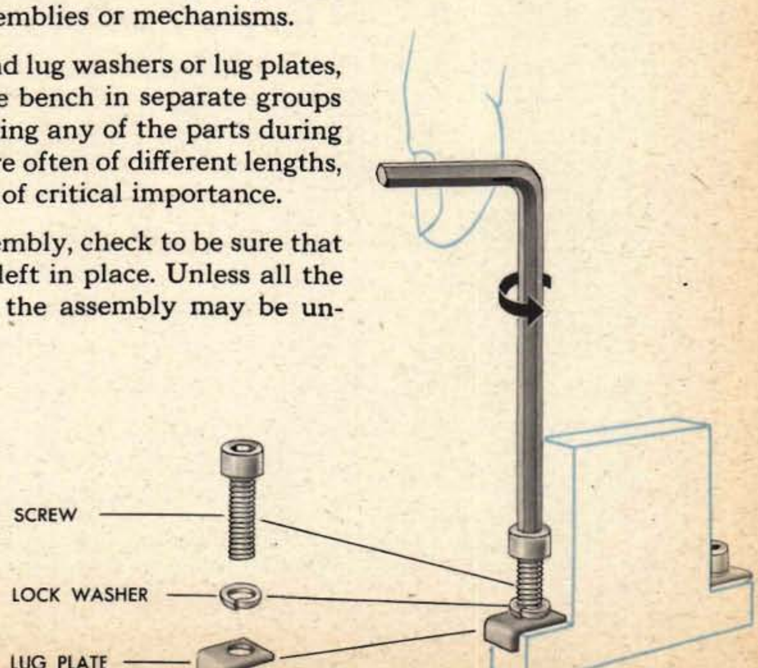
FOUR TYPES OF HANGERS



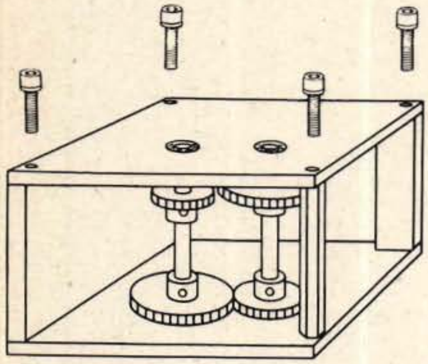
Hanger-positioned shaft assemblies are mounted on hangers which are fastened with screws to plates in an instrument. Two types of screws are used: slot-head screws and socket-head screws. During removal it is important not to drop any screws or other small parts into the instrument where they may cause a great deal of damage to other assemblies or mechanisms.

Remove the screws, lock washers, and lug washers or lug plates, and be careful to place them on the bench in separate groups with each screw to avoid interchanging any of the parts during reinstallation. Because the screws are often of different lengths, replacing them in the same holes is of critical importance.

Before attempting to lift out an assembly, check to be sure that no screw has been overlooked and left in place. Unless all the screws are loosened and removed, the assembly may be unnecessarily damaged.

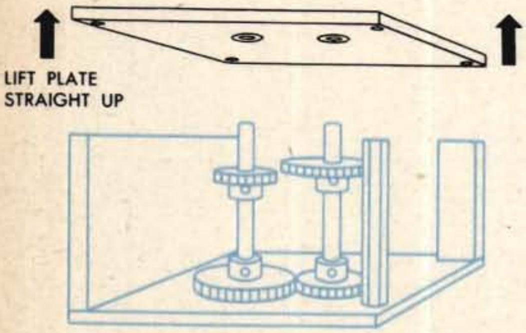


Removing plate-positioned assemblies

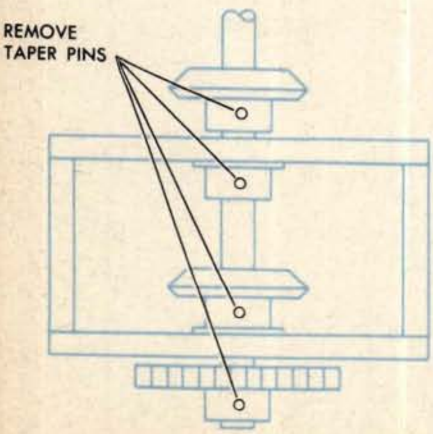


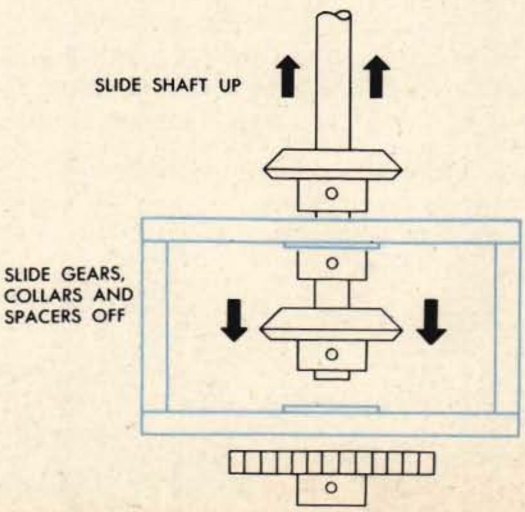
To remove a shaft assembly mounted between plates, it is often possible to remove the upper plate by unscrewing all the screws and lifting the plate straight up to clear the shafts.

If neither plate can be removed conveniently, it may be necessary to remove one or more taper pins in order to remove an assembly.



The screws and any accompanying small parts are removed in the same way as from hanger-mounted assemblies. In raising an upper plate, be careful to keep it parallel to the lower plate until the shafts are cleared. Be very careful not to lose any spacers that may adhere to the under side of the plate.



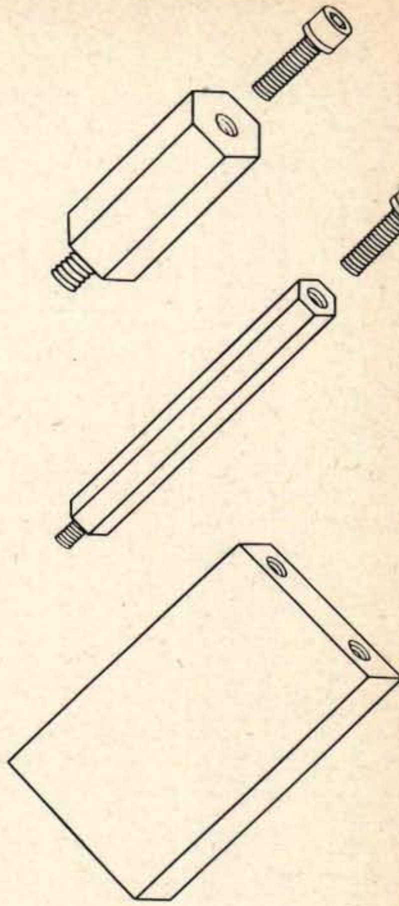


Some plates are supported by posts, or by both posts and plates.

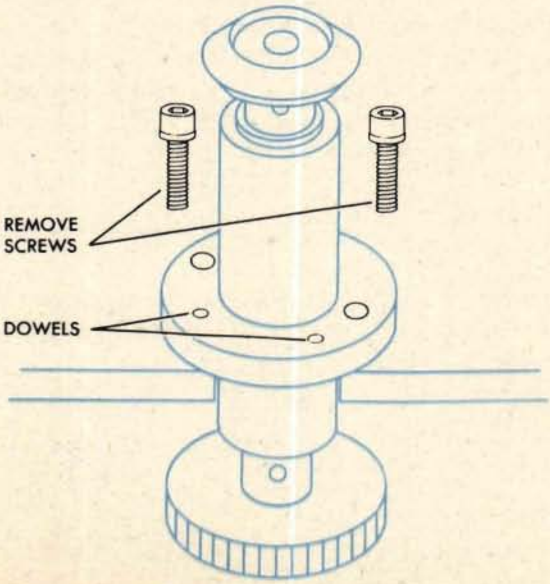
The most common type of post is a hexagonal bar with one end machined down and threaded to form a screw and the other end drilled and threaded to receive a screw.

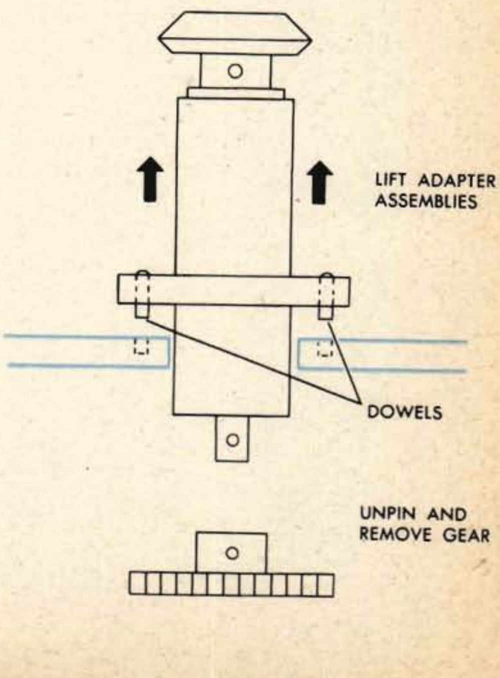
Another type is an oblong bar drilled and threaded at both ends to receive screws.

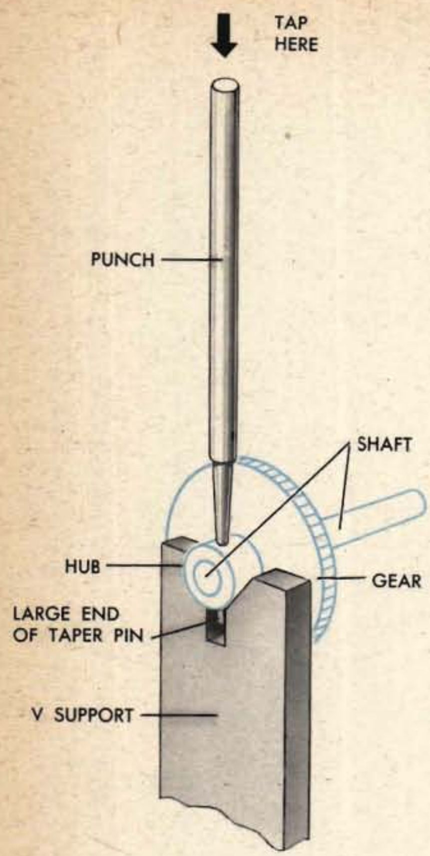
Plates may be removed from posts or posts from plates after the screws have been loosened and taken out. Most hexagonal posts can be unscrewed by hand, but sometimes a hole is provided to receive a round shaft which serves as a lever.



An adapter assembly is removed by taking out the screws and lifting the assembly straight up until the dowels clear the plate. Be careful not to cock the assembly during removal, because cocking it may bend or distort some part of the assembly.





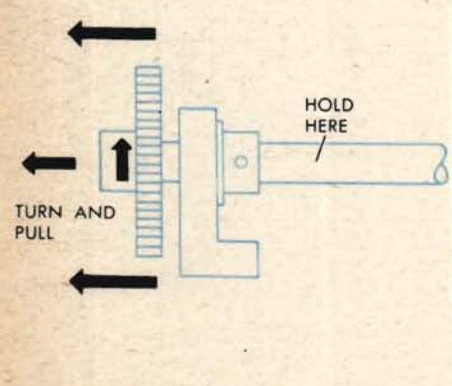


Unpinning and removing gears and collars

Always remember that most of the pins used to hold parts on shafts are tapered, and that a small amount of metal is staked over the large ends to hold the pins in place. It is therefore very important to start the pin out by tapping it sharply *from the small end.*

To avoid bending the shaft, place a V block or pinning support directly under the large end of the pin and keep the pin vertical. Use a light hammer and a pin punch held in a vertical position on the small end of the pin to drive it out. It is better to start the pin with a few light, sharp blows than with a heavy one which may bend or distort the parts. Once the pin is started, it should tap out easily.

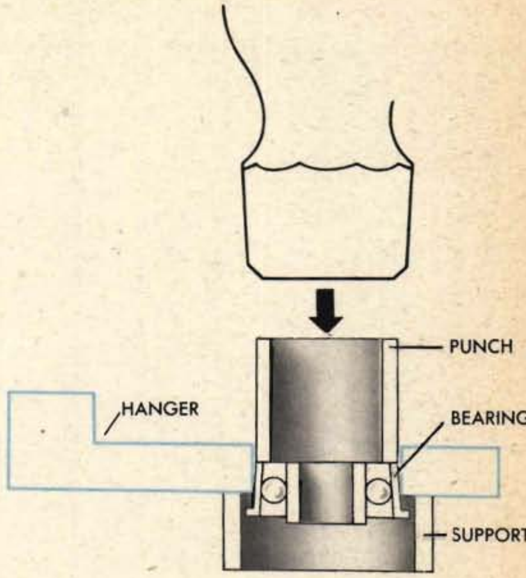
To remove a gear or collar after unpinning it, grasp the shaft in one hand and pull off the part with a slow, turning motion. If it cannot be removed this way, apply a drop of oil and tap the end of the shaft with a light hammer until it comes free.



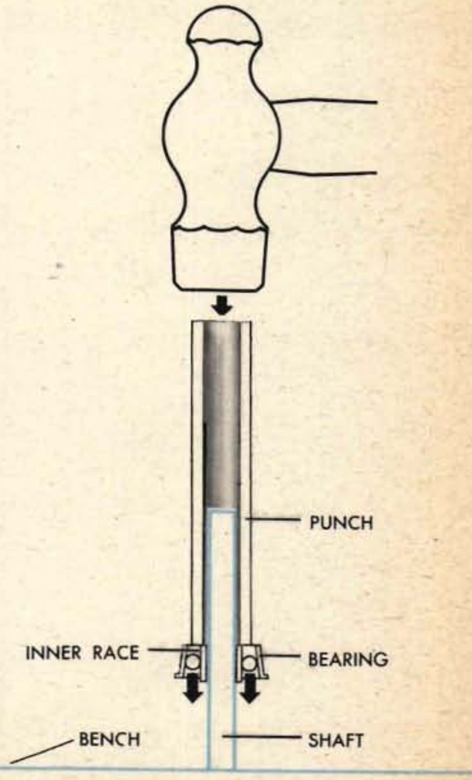
Filing off the burr formed on the shaft by the set screw will simplify removal of the other parts.

Removing bearings

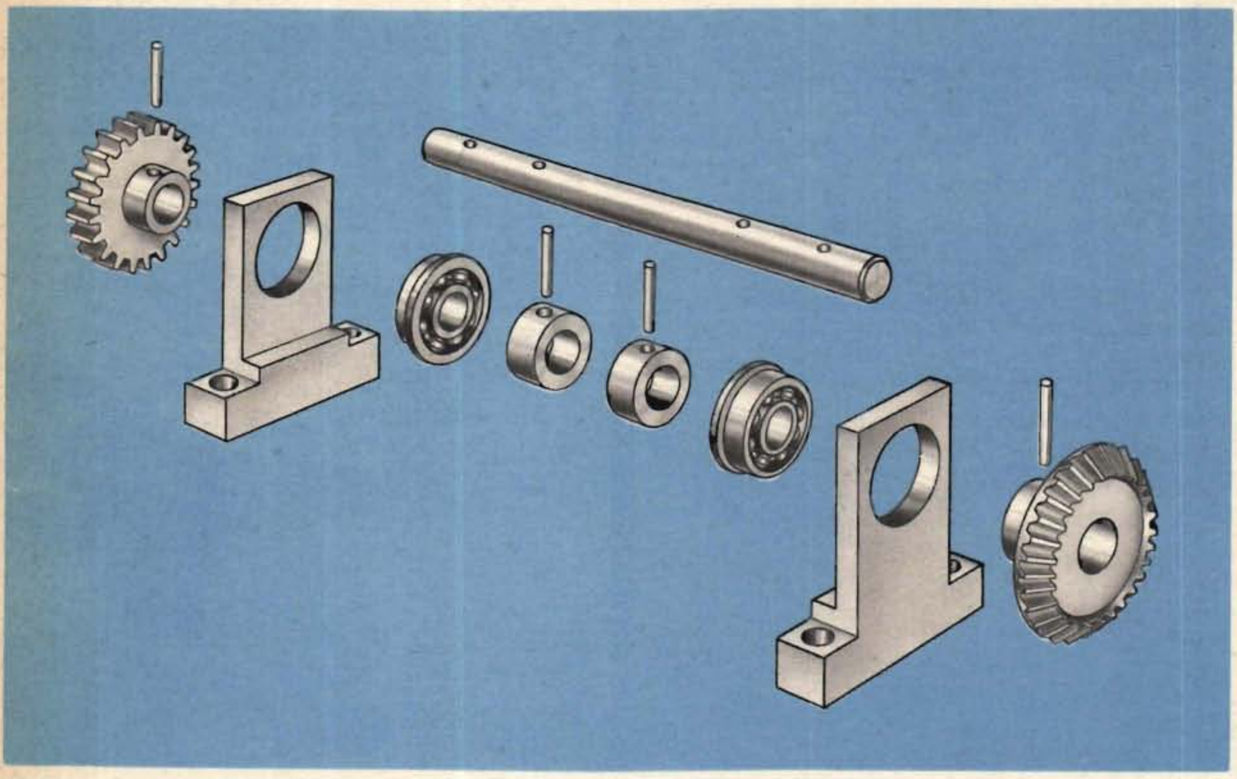
To remove a bearing from a hanger, use the bearing punch and the support described on page 30. The support is a piece of tubing of the proper diameter to fit around the bearing and up against the hanger. The punch is a piece of tubing which fits on the outer race of the bearing. Place the hanger on the support and the punch on the bearing Using a light hammer, tap the bearing punch until the bearing drops out of the hanger hole.

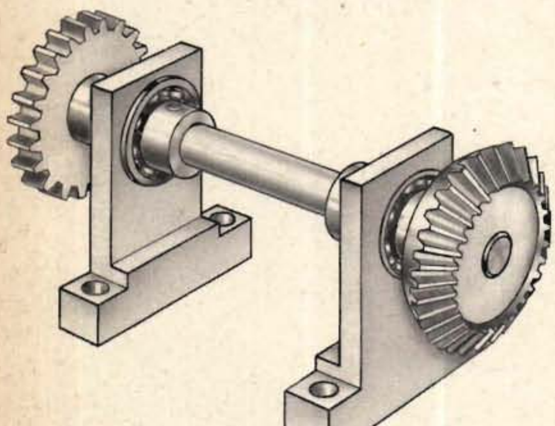


If a bearing freezes to a shaft, stand the shaft upright on the bench and slip a tubular bearing punch over the shaft. The punch must fit directly on the inner bearing race. Place a drop or two of oil on the shaft and tap the punch with a light hammer until the bearing comes loose.



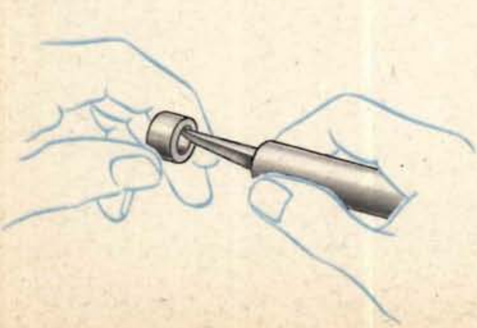
Preparing new parts





Here are new parts of a typical shaft assembly: one shaft, two hangers, two bearings, two collars, two gears, and four taper pins. The basic operations of preparing these parts for assembly may be applied to any shaft assembly repair job, in whole or in part, as required.

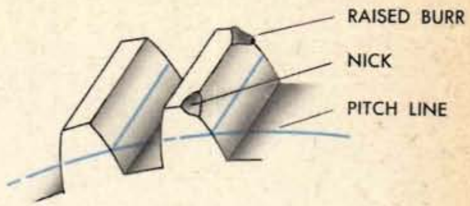
Whenever a new part is used, remove the rust-preventive coating.



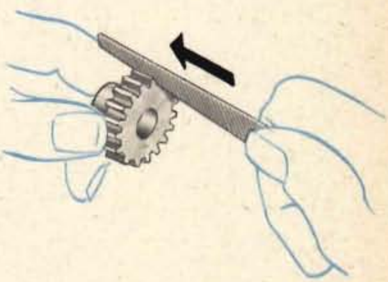
Scraping and filing the parts

Use a handscraper to break the sharp edges of the holes in the parts.

Inspect the gear teeth for nicks and burrs. Small nicks will not cause faulty operation of a gear, but a raised burr may cause meshing gears to bind.



Use a needle file to remove burrs. When filing a burr, be careful not to change the shape of the tooth.



Checking bearing smoothness

Check each bearing for smoothness. Hold it by the outer race in one hand, and turn the inner race with a finger of the other hand. Any roughness or stickiness indicates foreign matter in the bearing or some mechanical imperfection.

If the bearing does not operate smoothly, wash it in solvent, dry it, and check it again. Wash it several times, if necessary. If it is still rough or sticky, use a different bearing.

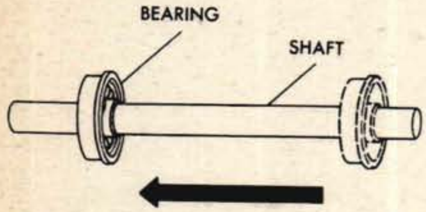
A bearing cannot be altered to fit a shaft or a hanger. If a bearing does not fit properly, the shaft must be reduced, or the hole enlarged in the hanger.

Washing the parts

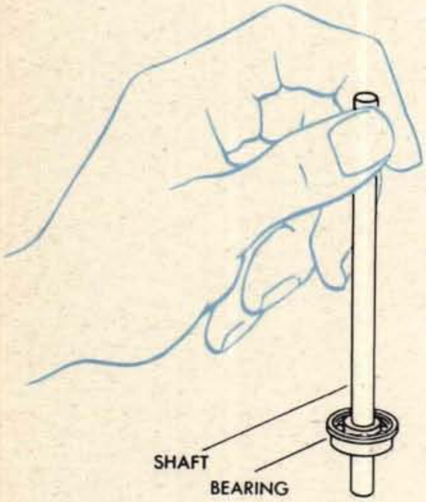
After the part has been prepared for installation, wash it thoroughly in solvent to remove dirt, grit, or chips. Dry and lubricate it before fitting.

Fitting the parts

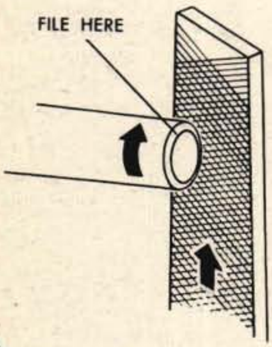
Fitting a shaft to a bearing



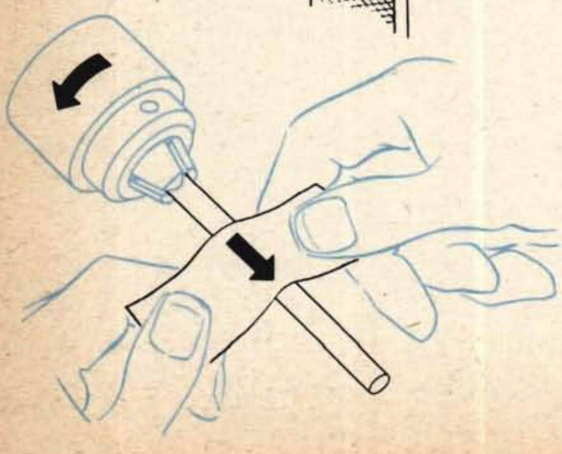
Before trying a bearing on a shaft, wipe the shaft with an oiled rag to prevent sticking. During all shaft-fitting operations, try the bearing frequently, wiping the hands and the shaft clean each time the bearing is handled.



A properly fitted shaft will allow the bearings to be pushed over its entire length by hand, but will not let them slip off if it is held in a vertical position.



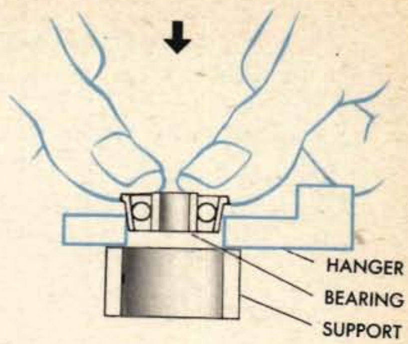
If a bearing does not go on a shaft properly, do not attempt to force it on. Forcing a bearing may damage the balls or raceways, or spring the retainer. Run a file lightly around the chamfered ends of a shaft to remove the burrs, and try the bearing again.



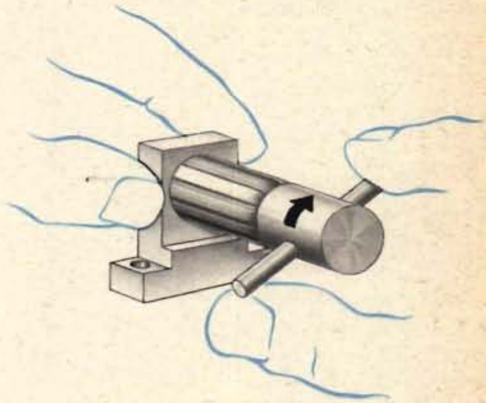
If a bearing will not pass over the entire length of the shaft without sticking, polish the shaft evenly, until the proper fit is obtained. This may be done by hand, but a smoother and more even job can be done if the shaft is rotated in a chuck mounted on a lathe, motor, or drill press. Try the bearing on the shaft frequently to avoid reducing the shaft too much.

Fitting and seating a bearing in a hanger

Start the bearing into the hanger hole from the side indicated on the assembly drawing. If the fit is correct, the slightly tapered bearing will press against the sides of the hole when the bearing is about 1/32 inch from the seat.

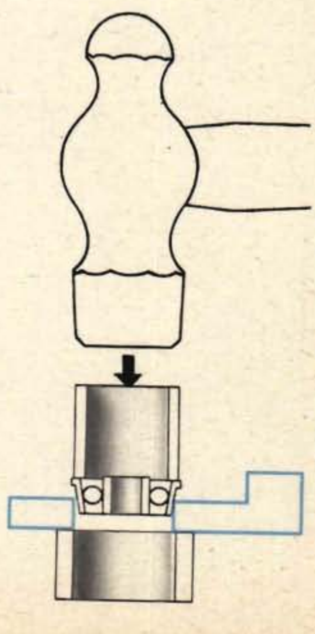


If the bearing cannot be pressed into the hole the proper distance by hand, the hole must be enlarged a little with a special bearing reamer. It is important to insert the reamer from the same side as the bearing, because this reamer has a slight taper. Float the hanger by allowing it to take its own position on the reamer without any hand pressure. Enlarge the hole slightly by slowly turning the reamer. Remove only a small amount of metal before trying the bearing in the hole.

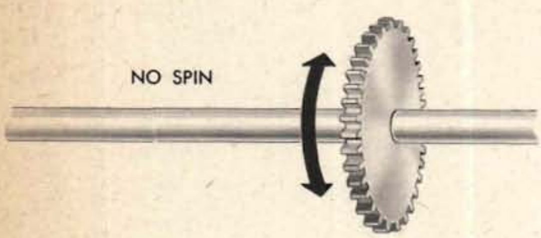


When the proper fit is obtained, seat the bearing. Use a light hammer and the punch and support described on page 30. The support fits around the bearing hole and against the hanger. The punch must fit over *the outer race* of the bearing.

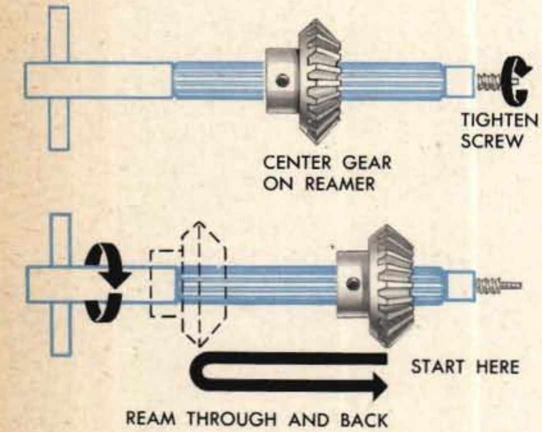
Finally, check the bearing for smoothness and wash the assembly.



Fitting gears and collars to a shaft



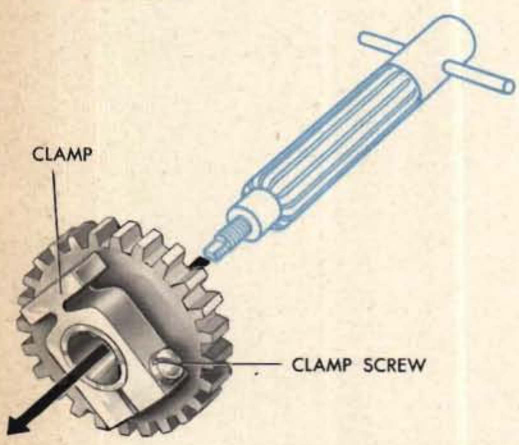
Collars and gears should fit on the shaft with a sliding push-fit. If they can be made to spin on the shaft, they are too loose and should not be used.



If a collar or gear is too tight, enlarge the hole with an expansion reamer the same size as the shaft. Before reaming, back out the set screw to avoid damaging the reamer. Position the gear or collar over the center or largest part of the reamer. Tighten the reamer screw until a slight drag is felt when the reamer is moved. Now turn the full length of the reamer through the hole and then draw the reamer back out. Try the collar or gear on the shaft. Repeat the reaming operation if necessary until the hole is the proper size for a sliding push-fit.

After the collar or gear is properly fitted, insert the set screw and mount the part in its approximate position on the shaft.

REAMING A CLAMP



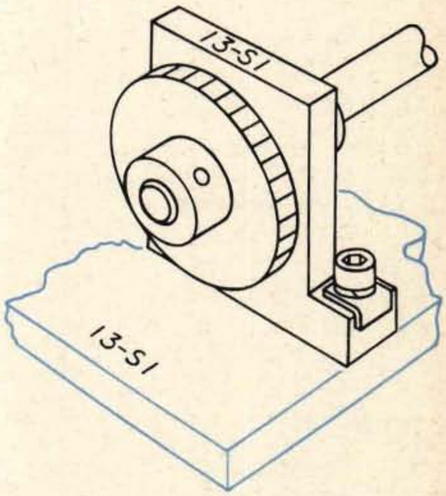
Fitting a clamp gear to a shaft

If a clamp gear is too tight, slip the clamp over the adjustable split gear hub before reaming the hole. Do not tighten the clamp screw, but turn it until it just takes hold. Start the reamer into the hole from the solid end of the hub. Ream the hole according to the directions given above for collars and gears.

Mounting an assembly on a plate

Positioning hangers

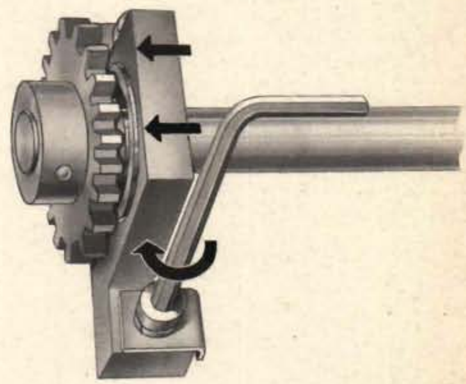
Hangers are usually positioned and held in place on a plate by means of screws, lock washers, and lug plates. The holes in the plate are accurately located to make it possible to position each hanger within close limits.



The shaft assembly number indicated on the drawing should be stamped or etched on a new hanger before it is installed. In mounting a new hanger, remember that lock washers will damage any material softer than steel. Always use lug plates, lug washers, or straddle plates between lock washers and any softer material.

Always remember to lubricate the screws before inserting them.

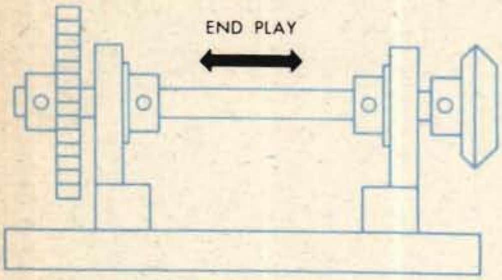
To square a hanger, move it toward its end of the assembly and against the screws before tightening the screws.



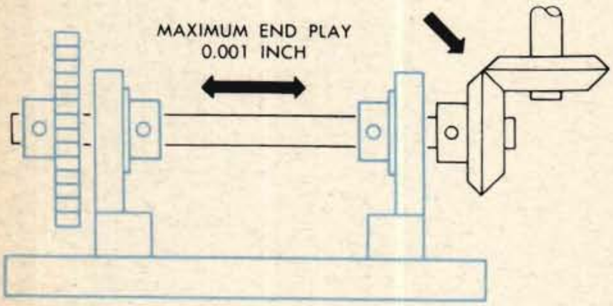
SQUARING A HANGER

Often a mounted hanger can be repositioned by loosening the screws and shifting the hanger slightly in the required direction. If screws are loose or missing, a hanger can be repositioned and held by tightening or replacing the screws.

Reducing end play

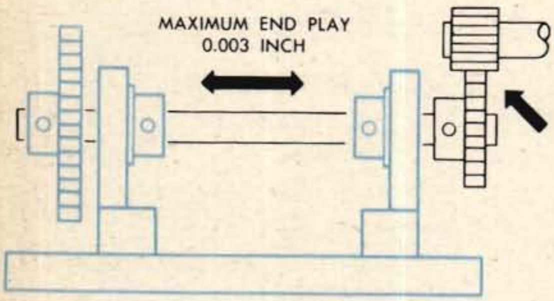


End play is the lengthwise, or back-and-forth, movement of a shaft within its assembly. Gears and collars press against the bearings and thus control end play in a shaft assembly.

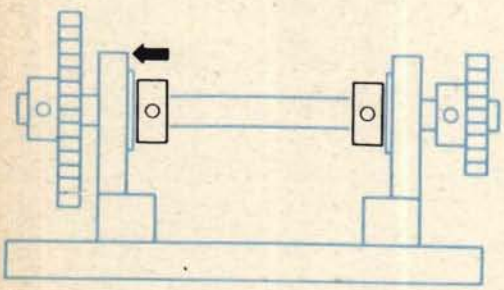


Beyond very small limits, end play is undesirable because it affects the gear meshes.

A shaft with one or more bevel gears should have no more than 0.001-inch end play.

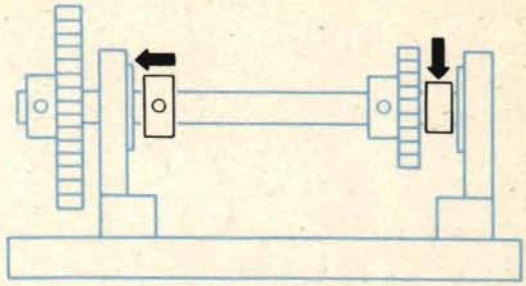


A shaft with spur gears only may have up to 0.003-inch end play.

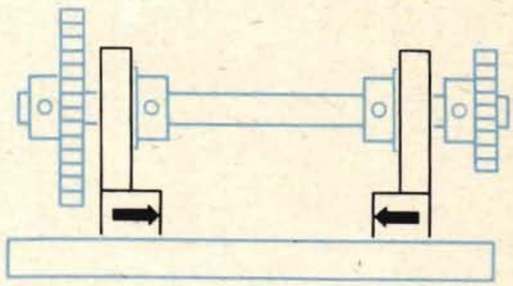


Move the collar or gear against the bearings until end play cannot be felt, yet the shaft turns freely. Then tighten the set screw to hold the collar or gear in position until it is pinned.

Excessive end play can often be remedied by repositioning a collar at one end of an assembly, or by installing a longer spacer at the other.

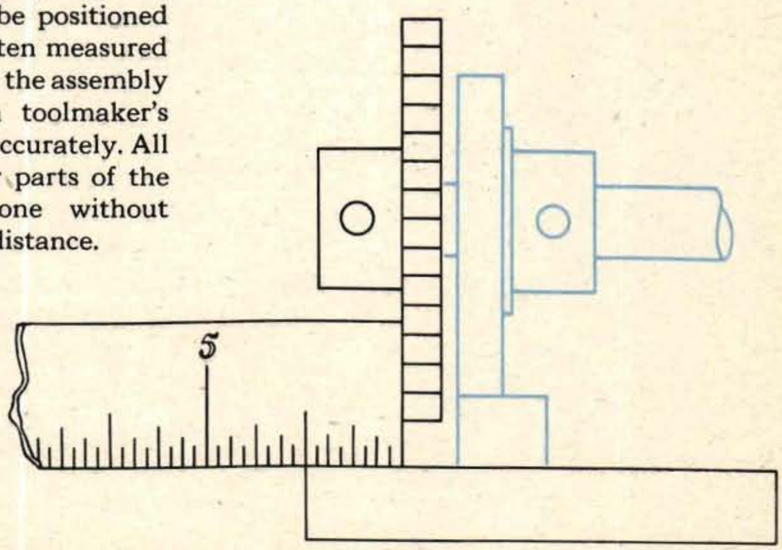


Sometimes end play can be reduced sufficiently by loosening the hangers and moving them in the proper direction.

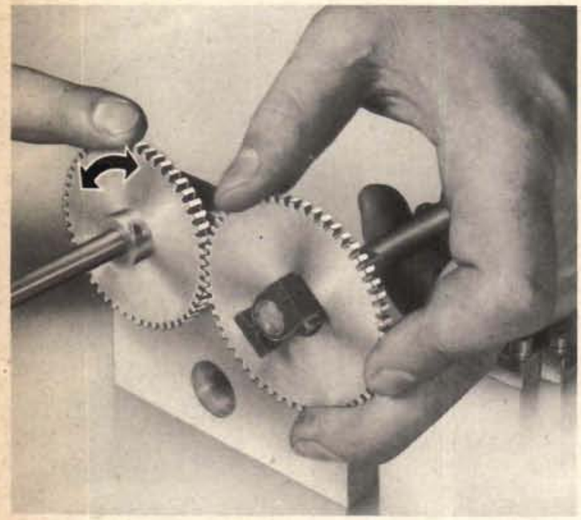


Positioning a gear to a given dimension

An assembly drawing may specify that a particular gear must be positioned to a given dimension, often measured from the side of the plate the assembly is mounted on. Use a toolmaker's scale to position a gear accurately. All positioning of the other parts of the assembly must be done without changing this specified distance.



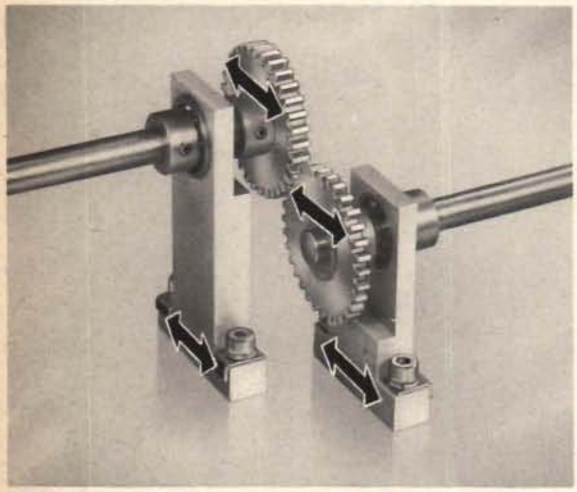
Positioning gears for proper mesh



Properly meshed gears make contact evenly all along the surfaces of the teeth, with only a very small amount of lost motion between the teeth of one meshing gear and those of the other.

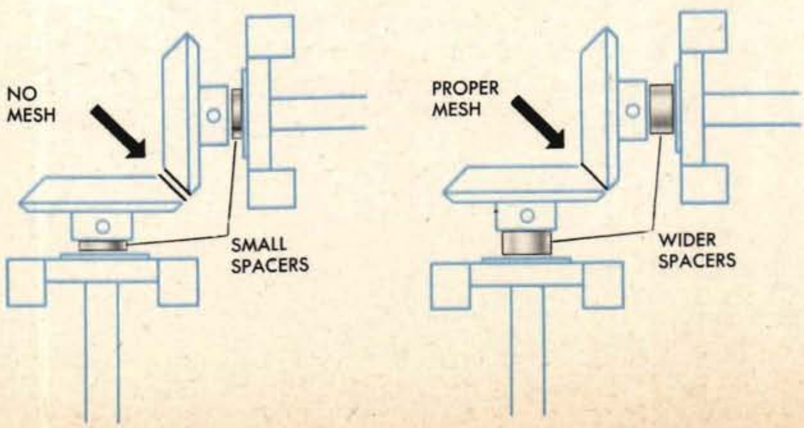
Lost motion is the distance the driver gear turns before the driven gear begins to turn.

It may be measured with a dial indicator, or estimated by holding one gear stationary and gently rocking the other.

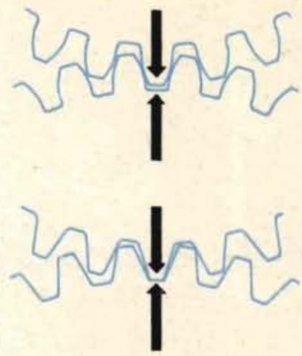


If there is no lost motion at all, the gears are too tight. If there is over 0.002 inch, they are too loose. Either tight or loose gears must be repositioned.

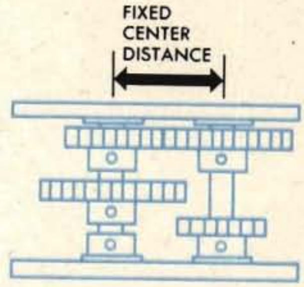
Gears can be positioned for correct lost motion by moving them together or apart by various mechanical means, according to the particular assemblies. Hangers may be shifted slightly, spacers and collars may be filed or longer spacers installed, or a gear may be moved into a new position on its shaft.



If the teeth are worn too much, new gears should be installed. New gears are cut so that there is a clearance between the tops of the teeth on one gear and the bottom of the spaces between the teeth on the other. If the teeth are worn so that this clearance is lost when gears are moved together, they are said to bottom. Never attempt to reduce lost motion in gears which bottom, because they cannot be made to run smoothly. They must be replaced.



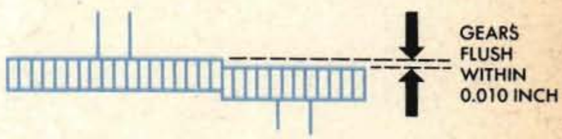
Gears on a fixed center distance cannot be moved to reduce excessive lost motion and therefore must be replaced.



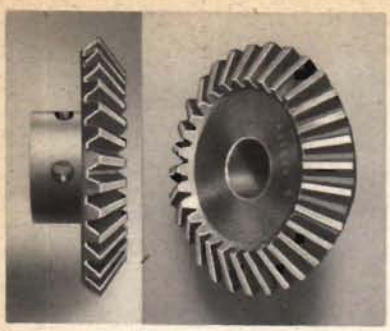
Positioning spur gears

Spur gears should be positioned for correct lost motion and proper alignment of the gear faces. There should be some lost motion, but not over 0.002 inch.

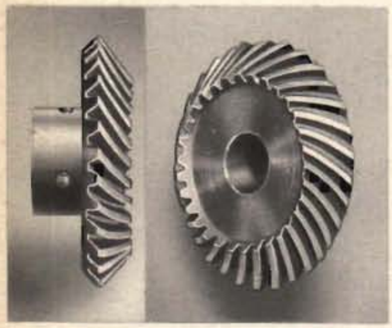
If the gears are of the same thickness, their faces should be flush within 0.010 inch after they have been adjusted for correct end play.



If they are not of the same thickness, the thinner one should be centered on the other.



STRAIGHT-TOOTH BEVEL GEARS

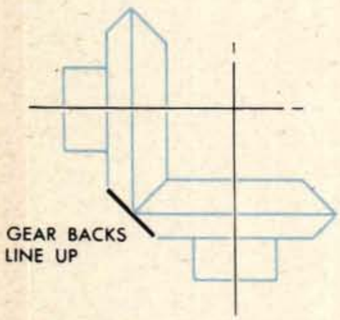


SPIRAL-TOOTH BEVEL GEARS

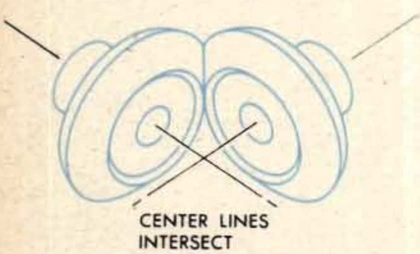
Positioning bevel gears

Because bevel gears are always mounted at an angle to each other, positioning them involves special problems. The spiral-tooth and the straight-tooth bevel gears are the two types in common use. The procedure for positioning them is the same for both, except that the curved teeth of the spiral bevel gear make each movement more critical. Care must be exercised in positioning either type, but very particular care must be taken to obtain a correct spiral bevel gear mesh.

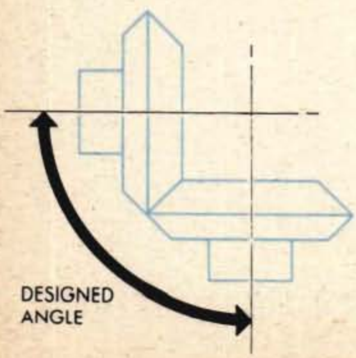
Essentials of a good bevel gear mesh



The backs of the gears must line up.



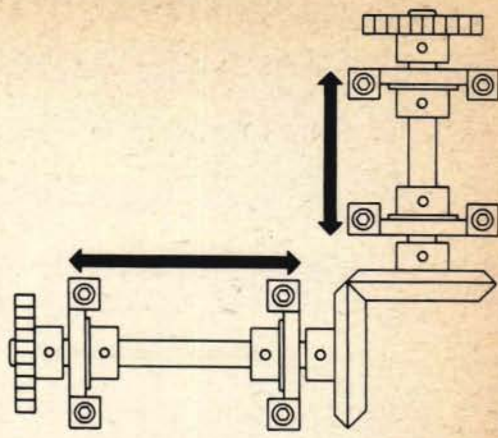
The centerlines must intersect. If the bearing holes in the hangers are the same height from the plate, this condition is established.



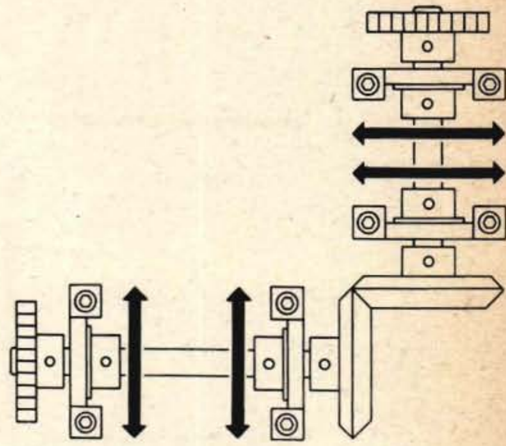
The gears must mesh at the angle for which they were cut.

If these three essentials of a good bevel gear mesh have been satisfied, the gears will run quietly and smoothly. Proper lubrication will prevent undue wear. The wearing action of normal operation should make the tooth faces appear uniformly smooth.

As a general rule, it is best to obtain a proper bevel gear mesh by moving both shaft assemblies equal distances *in the direction of their shafts* rather than sidewise.

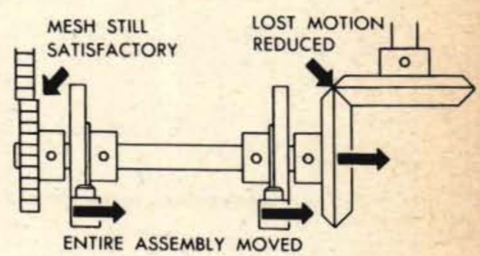


But there are exceptions. Sometimes both *entire* shaft assemblies can be moved together or apart by shifting all four hangers a little to one side or the other. If a shaft is very long, a slight sidewise shift at one end may not seriously affect the mesh at the other. To determine the best way to position a bevel gear mesh, closely examine all the affected gears and the related shafting and gearing.

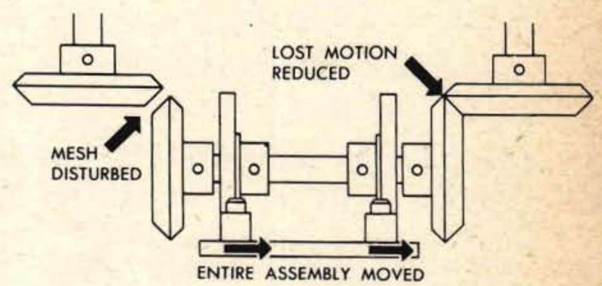


Moving bevel gears in the direction of the shaft

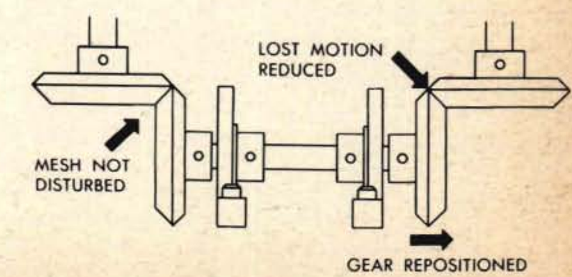
A shaft assembly having only one bevel gear can be positioned to reduce lost motion or to free a tight mesh more easily than an assembly having two or more bevel gears.

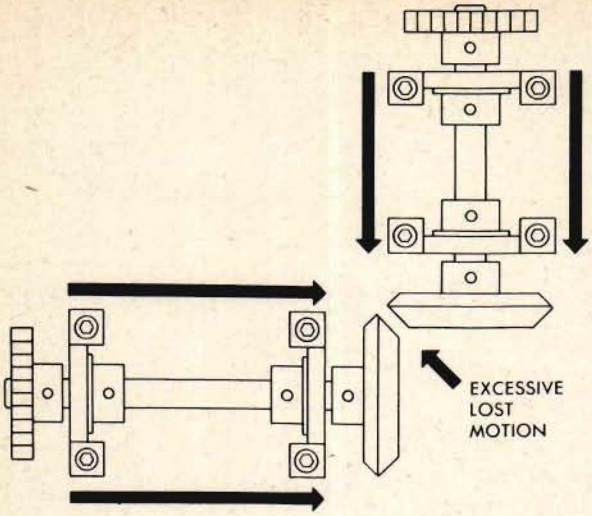


If an assembly with two or more bevel gears is moved to improve one bevel gear mesh, the other meshes may be disturbed.

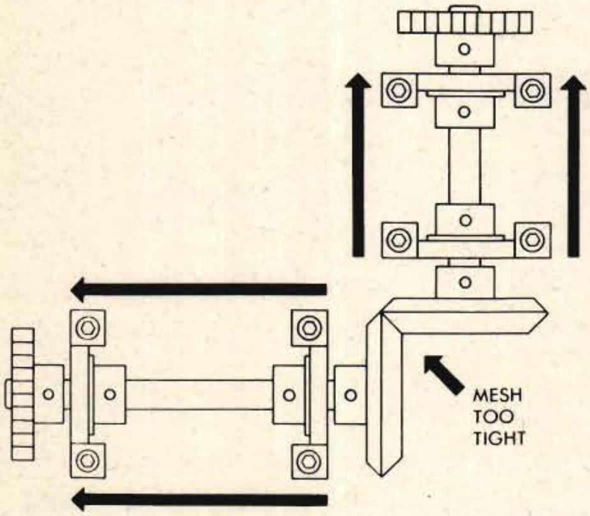


To avoid this, it is often necessary to unpin and move the particular gear which must be repositioned. For an explanation of the method of moving a gear, see pages 66-67.

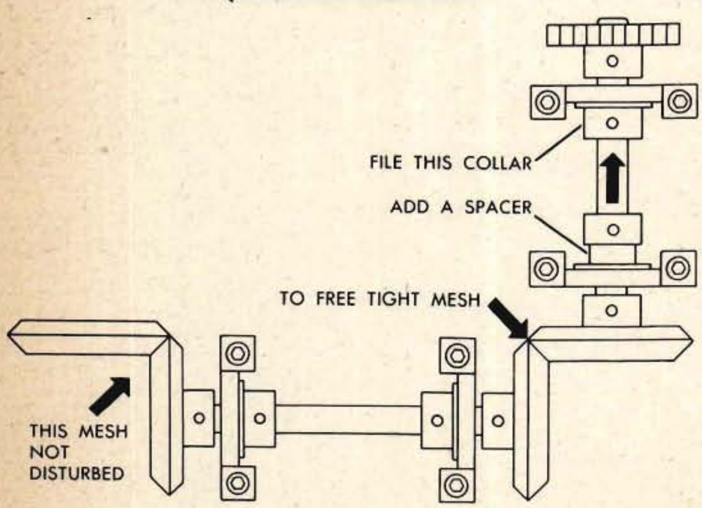




TO REDUCE LOST MOTION in a bevel gear mesh where each assembly has only one bevel gear, move both assemblies in the direction of the shaft *toward* the meshing gears. Shaft assemblies mounted on hangers may be moved by loosening the screws and shifting the hangers. The hanger holes may be enlarged slightly, if necessary.

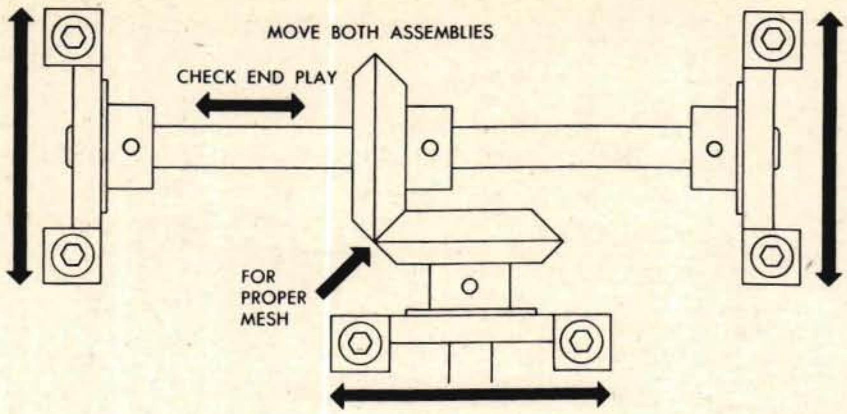


TO FREE A TIGHT BEVEL GEAR MESH, move both shaft assemblies in the direction of the shaft *away from* the meshing gears. Check the assemblies for correct end play.



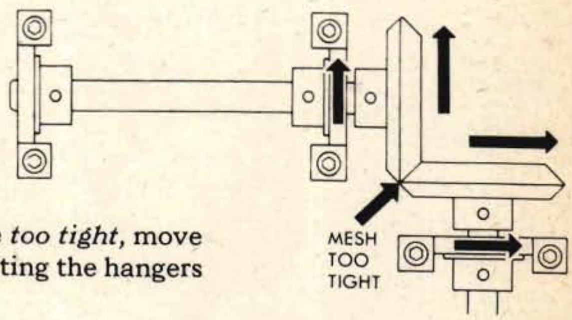
Sometimes it is necessary to install thicker spacers, or to file collars or spacers in order to obtain a good bevel gear mesh. To reduce the thickness of spacers and collars most accurately, use the spacer-filing fixture described on page 31.

Moving bevel gear assemblies sidewise

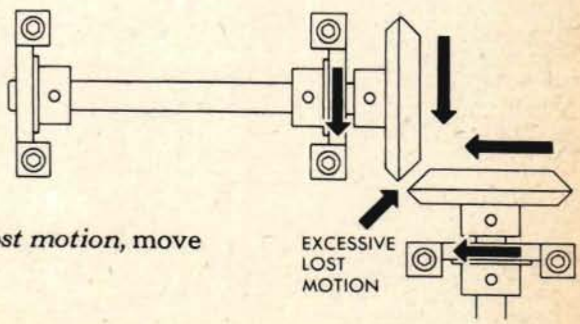


Often bevel gears can be repositioned most easily by shifting hangers slightly to one side or the other. It is important to move each assembly the same distance as the other, and at the proper angle. Whenever a hanger is moved, the whole assembly should be checked for correct end play. It may be necessary to install a thicker spacer, or to file a collar or spacer.

To obtain a good bevel gear mesh where the assemblies have been in use, first inspect the gear teeth for wear.

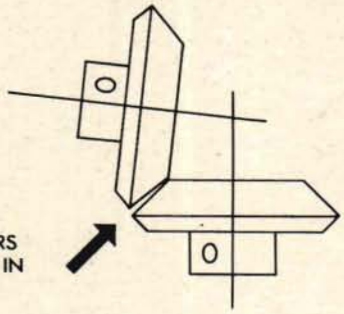


If they are worn evenly and the mesh is a *little too tight,* move the assemblies apart at the affected ends by shifting the hangers slightly sidewise.

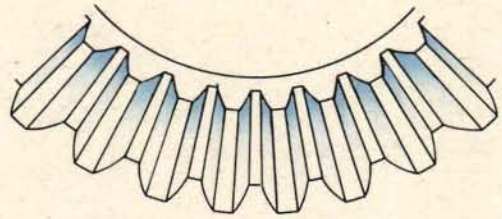


If they are worn evenly and there is *excessive lost motion,* move the assemblies together in the same way.

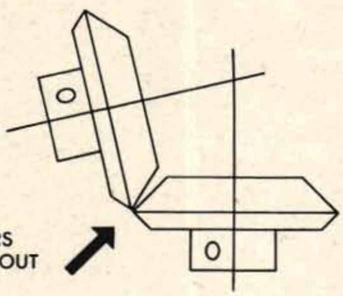
If bevel gears toe in—that is, they mesh at an angle greater than the angle for which they were designed—signs of wear appear on those areas of the tooth faces nearest to the center of the gear.



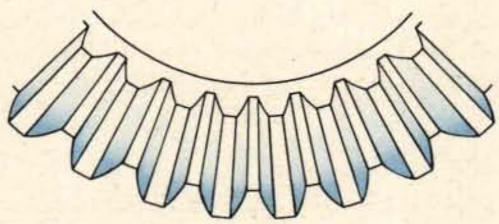
GEARS TOE IN



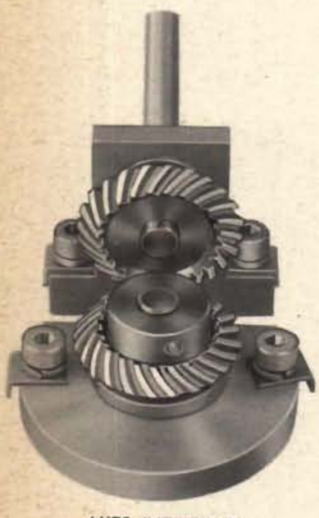
If they toe out, signs of wear appear on the areas of the tooth faces farthest from the center of the gear.



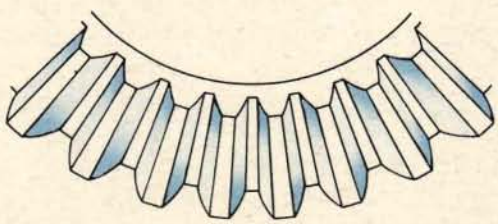
GEARS TOE OUT



The shaft axes of meshing bevel gears must intersect. If they do not, the mesh will feel rough and sound noisy even though the end play and lost motion seem to be correct. Signs of wear will appear on the opposite ends of alternate tooth faces, as shown.



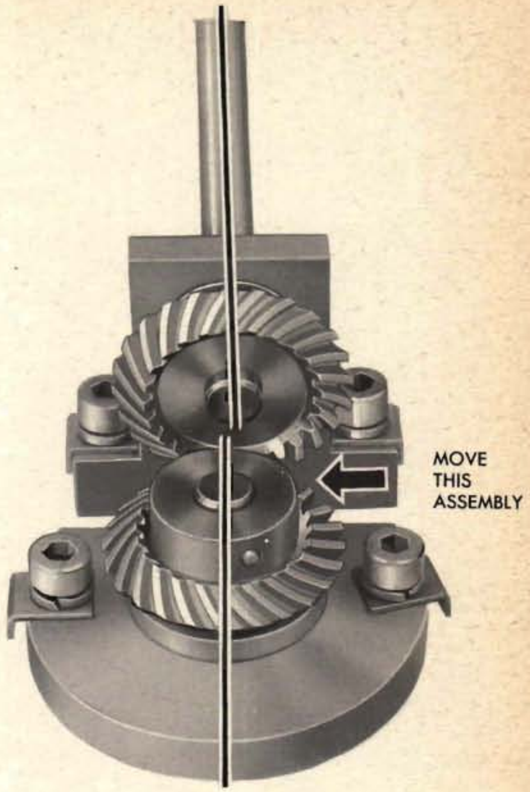
AXES INTERSECT



Bevel gear meshes most susceptible to this type of misalignment are those where one shaft is parallel to the mounting plate and the other is perpendicular to it.

A very slight movement of a hanger within the limits of the clearance holes will cause a marked difference in a bevel gear mesh. If the shaft axes do not intersect, loosen one of the hangers and move the shaft assembly sidewise until the shaft axes appear to be correctly aligned. Then check the mesh for freedom of movement.

When the shafts are properly aligned and the gears turn freely, check the assembly for end play and lost motion. Secure the assembly in place. Recheck the gear mesh for freedom of movement and lost motion, and the shaft for end play.

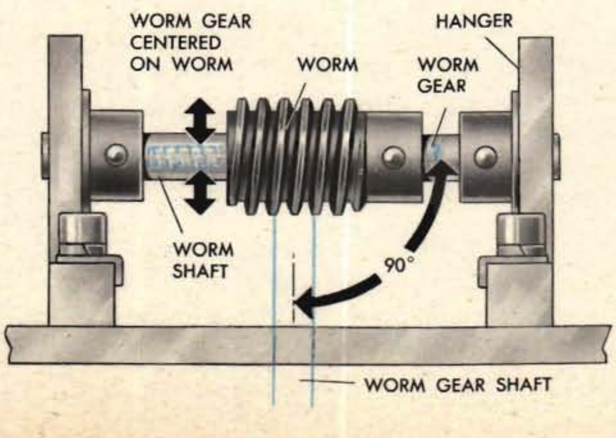


AXES NOT INTERSECTING

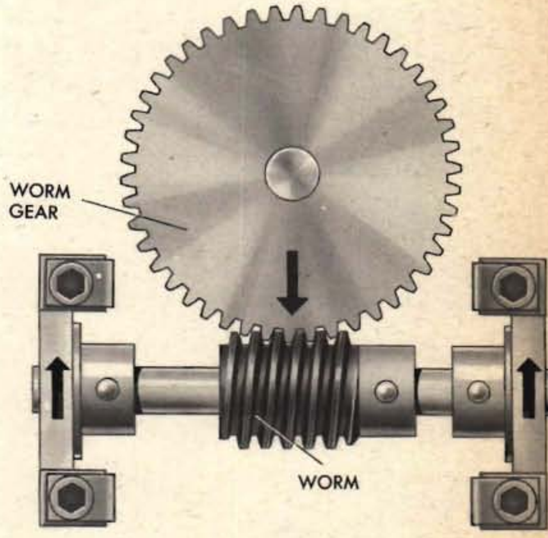
Positioning worm gears

A good worm gear mesh is obtained by moving whichever gear can be moved most easily toward the other. The worm gear must be centered on the worm and the two shafts positioned at right angles to each other.

For efficient transmission of values, lost motion between the worm and the wheel must be kept at a minimum. End play in the worm shaft must also be kept at a minimum because it has the same effect on the mesh as lost motion between the gears.

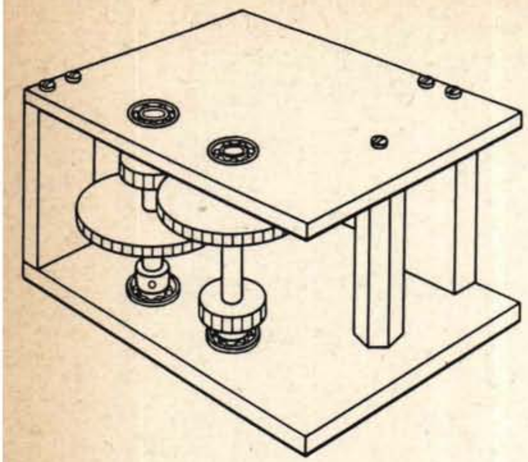


SIDE VIEW



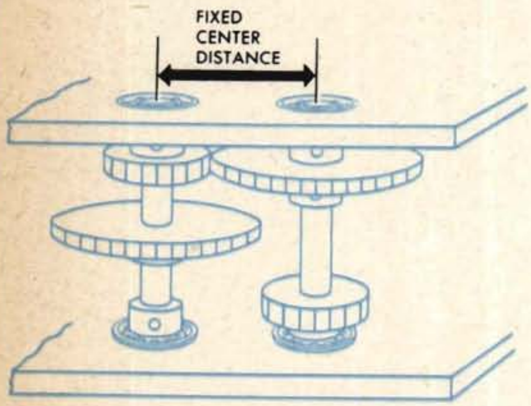
TOP VIEW

Positioning gears in a box assembly

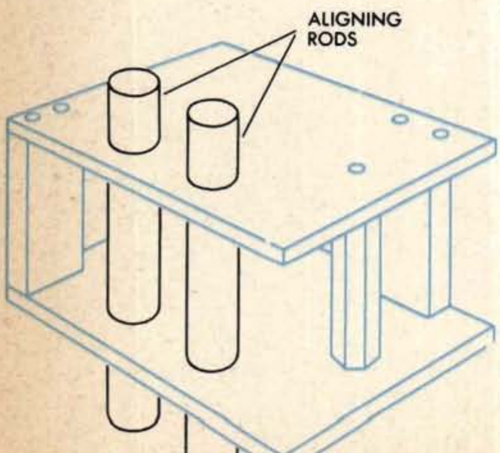


In a box type of assembly, gears cannot be easily repositioned because the shafts are mounted in bearings fitted in fixed plates instead of movable hangers.

End play may be reduced by installing longer spacers, or increased by filing collars or spacers.



Lost motion at the gear meshes is not so easily controlled, however. Because of the fixed positions of the shafts in the bearing holes in the plates, each pair of meshing gears is positioned at a fixed center distance. When the construction of the parts establishes a fixed center distance, lost motion due to worn gear teeth can be reduced only by installing and fitting new gears.

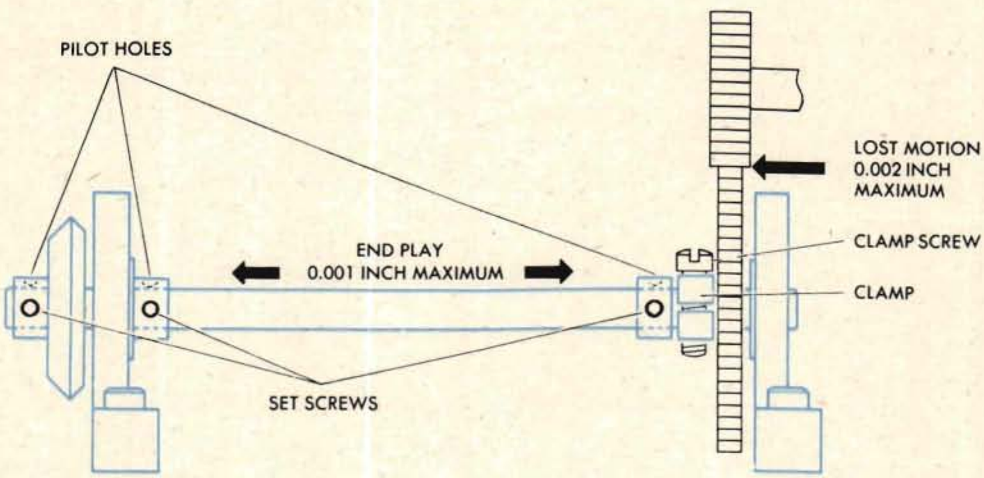


For proper operation, the plates must be parallel with each other, and the bearing holes must be perfectly aligned. The alignment may be checked by pushing close-fitting rods through the holes. Lubricate the rods before making this test.

Pinning the parts

After the parts of a shaft assembly have been correctly positioned in the instrument and the set screws have been tightened, the entire assembly must be removed for pinning. A complete pinning operation includes drilling the holes, seating the pins, and staking the pins. Each of these steps must be done very carefully.

Essentials of a correctly positioned assembly



Before removing an assembly from an instrument for pinning, check to be sure that the following five conditions have been established:

All pilot holes in hubs and collars should be in a straight line, so that when the holes are drilled through the shaft, their centers will lie in approximately the same plane.

All set screws are in place and tight.

Clamp gears hold tight to the shaft when the clamp screws are tightened. The clamp must hold the hub on the shaft without a complete closing of the clamp slot.

Shafts with straight-tooth spur gears turn freely, with 0.0005 to 0.003 inch end play. Shafts with one or more bevel gears, worms, or helical gears, turn freely with not more than 0.001 inch end play.

Lost motion between gear teeth does not exceed 0.002 inch. This applies to spur, helical, bevel, and worm gears.

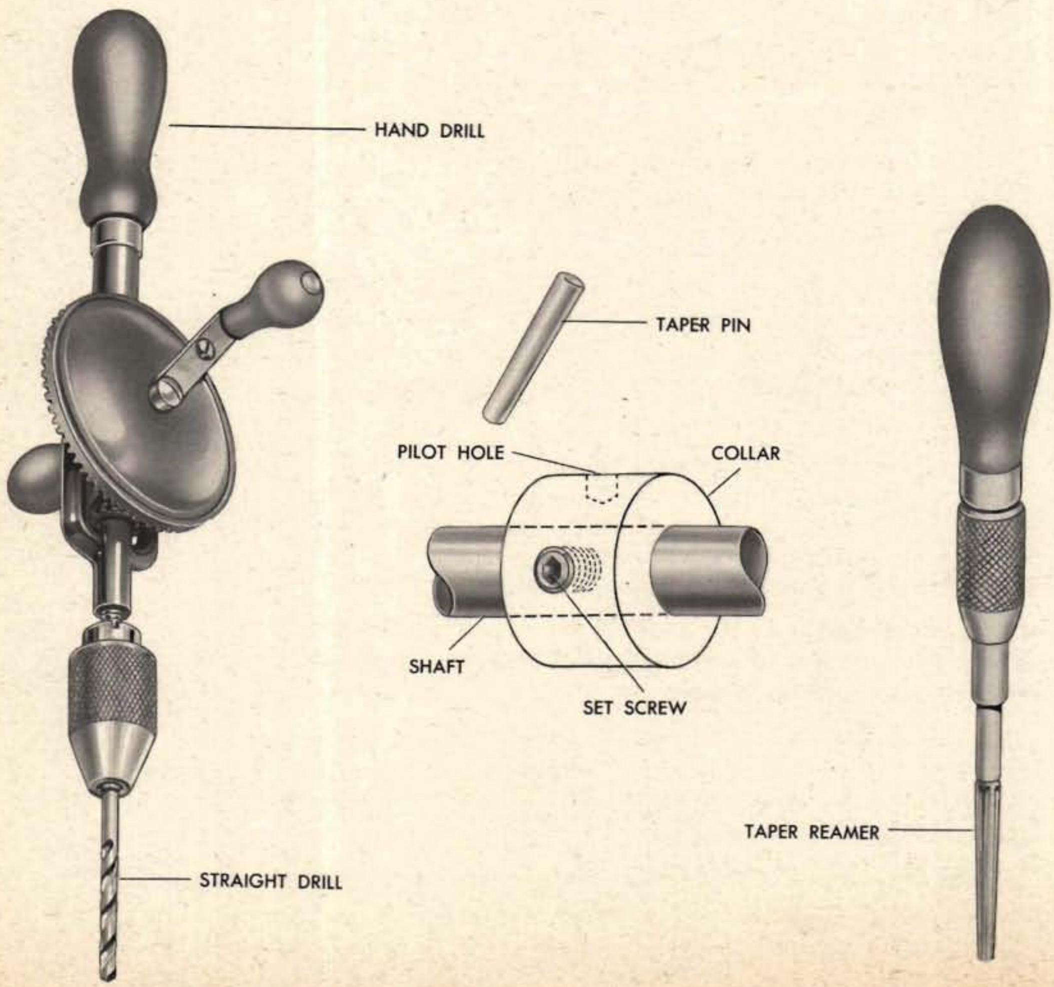
In removing a shaft assembly from the instrument for pinning, *be very careful not to disturb the set screws or nick the gears.*

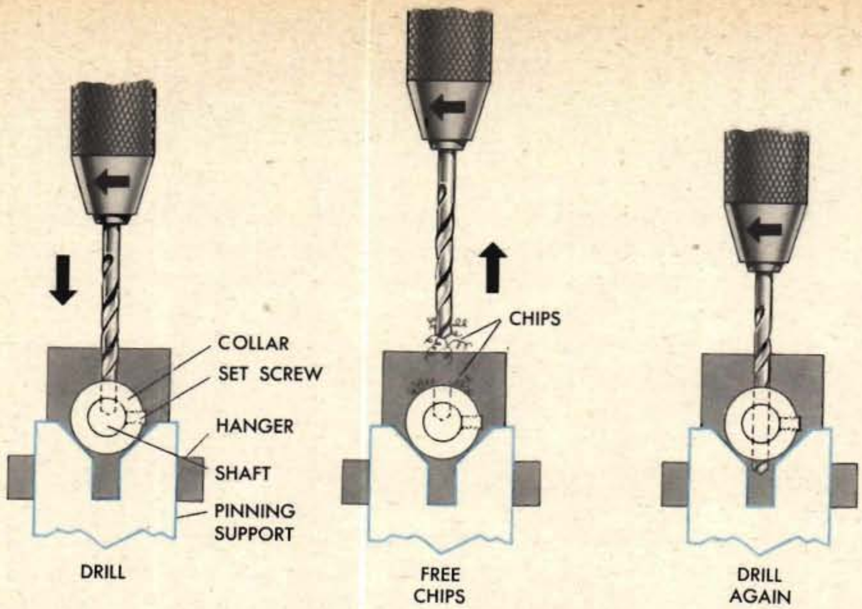
Drilling a shaft

There are two entirely different methods of drilling a shaft when a new gear or collar is used: a factory method for large-scale production, and a trouble-shooter's method for single repair jobs on the bench. Whichever method is used, the collar or hub is provided with a pilot hole spotted about halfway through one side to guide the drill.

The factory method involves using a taper drill in a drill press equipped with an automatic stop.

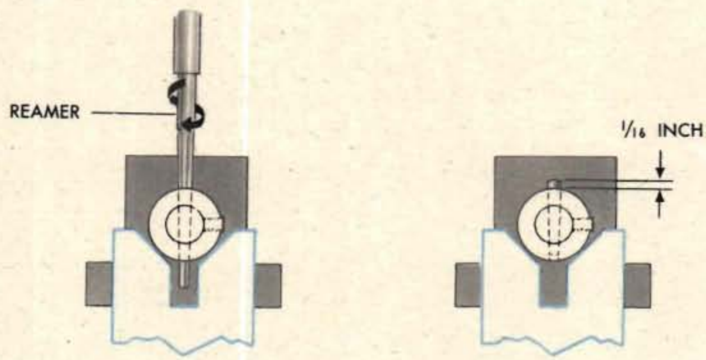
The trouble-shooter's method requires a standard straight drill, slightly smaller than the small end of the pin, and a taper reamer the same size as the pin. The taper pin must be selected according to the size of the shaft and the collar or hub to be pinned to it.



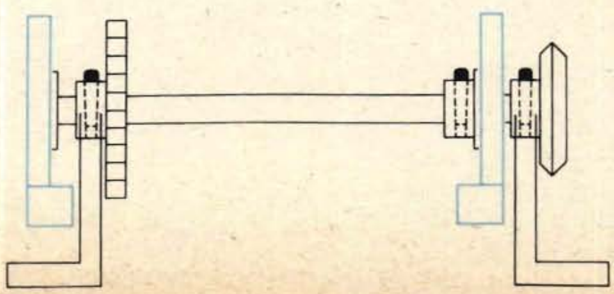


To avoid bending a shaft during drilling, it is important to place a pinning support directly under the collar or hub. The drill should be held perpendicular to the shaft axis. Lubricate the drill before using it, feed it slowly, and remove it from the hole often to free the metal chips. When the drill breaks through the opposite side of the collar or hub, remove it and clean out the hole.

Lubricate the hand taper reamer and ream the hole until the pin enters to within 1/16 inch of its final position.

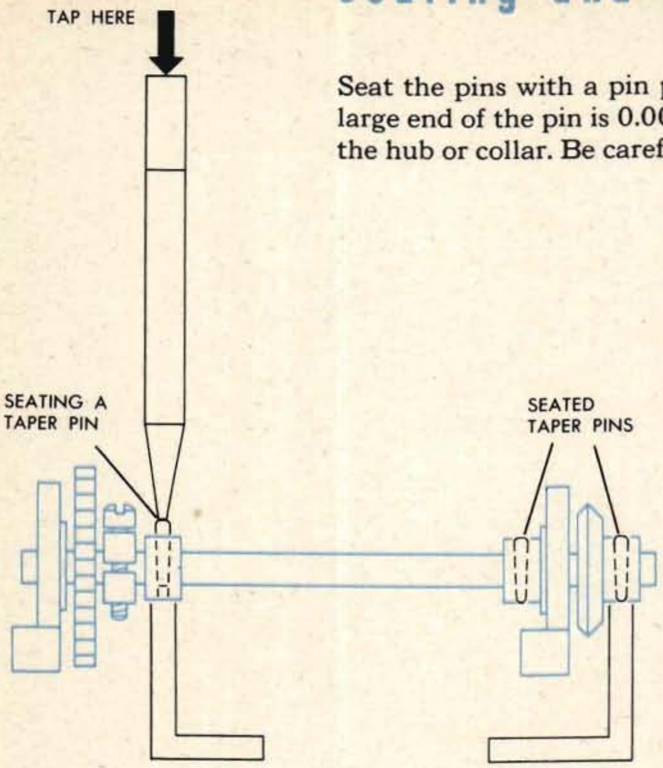


Drill and ream all the holes the assembly requires before seating the pins. After each hole has been drilled and reamed, insert the taper pin and leave it in place.

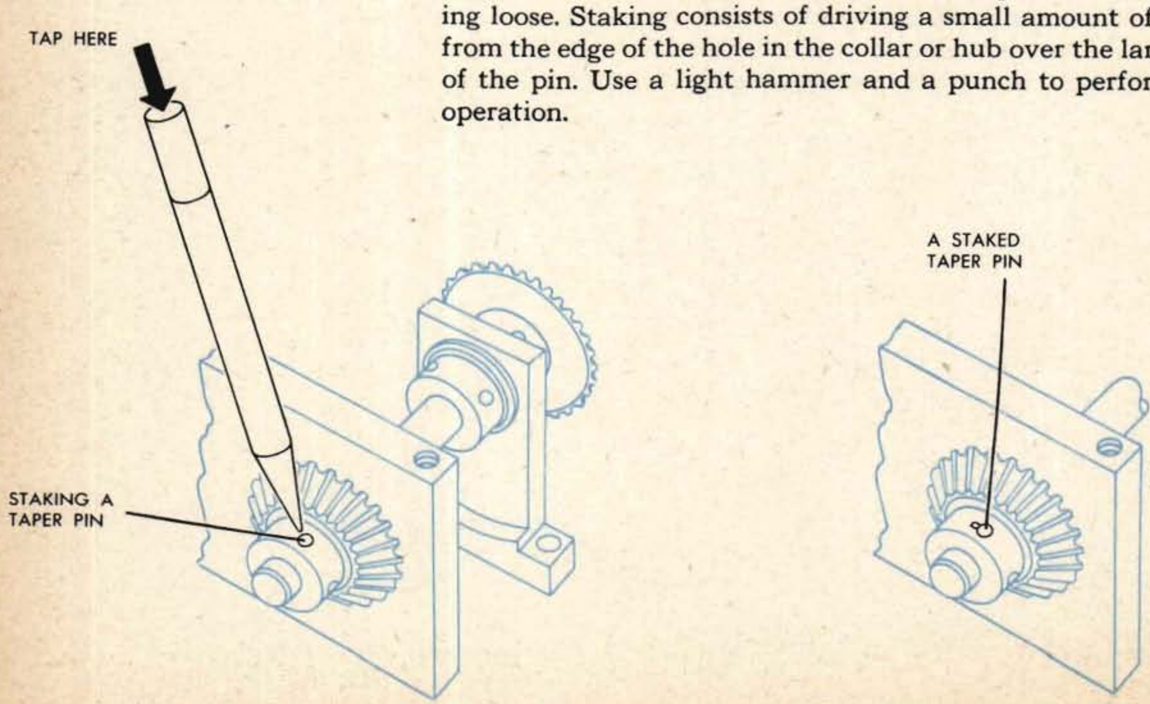


Seating and staking taper pins

Seat the pins with a pin punch and light hammer so that the large end of the pin is 0.005 to 0.010 inch below the surface of the hub or collar. Be careful not to bend the shaft.



The pins should be staked in position to keep them from working loose. Staking consists of driving a small amount of metal from the edge of the hole in the collar or hub over the large end of the pin. Use a light hammer and a punch to perform this operation.



Marking a gear position for pinning

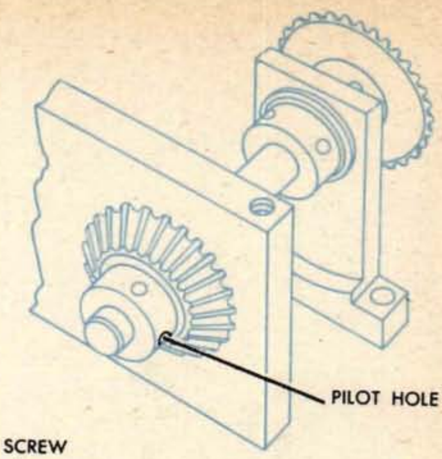
Sometimes a shaft is mounted through a plate with a gear on one side of the plate and the rest of the assembly on the other.

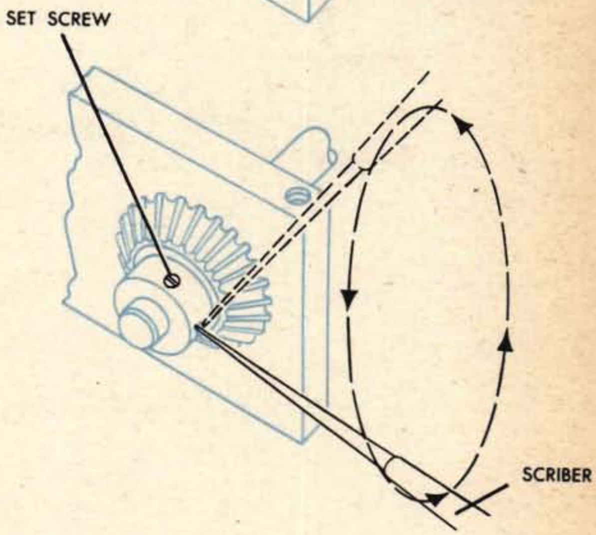
Before a new gear is mounted outside the plate for positioning, the pilot hole must be drilled through to the shaft hole so that the correct gear position can be marked on the shaft for drilling.

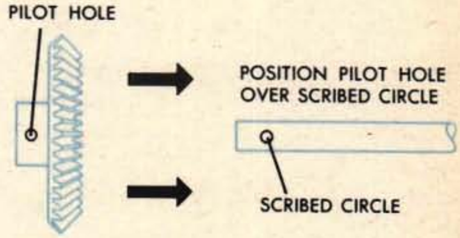
After the gear has been correctly positioned and held by a set screw, insert a thin scriber at a sharp angle through the pilot hole and scribe a circle on the shaft as large as the pilot hole. Then loosen the set screw, take off the gear, and remove the rest of the assembly from the instrument.

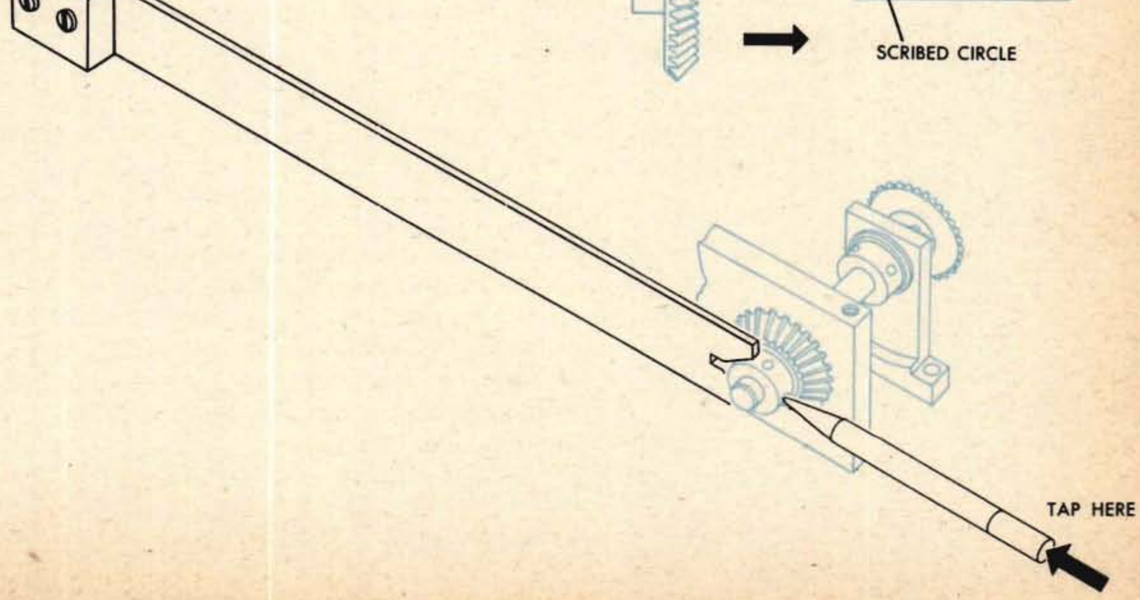
On the bench, remount the gear on the shaft and carefully align the pilot hole with the scribed circle on the shaft. Drill and ream the hole and insert the pin, but do not seat it until all the other parts have been pinned and the entire assembly remounted in the instrument.

Seat this pin when the assembly is in place, using the back-up tools described on page 29..

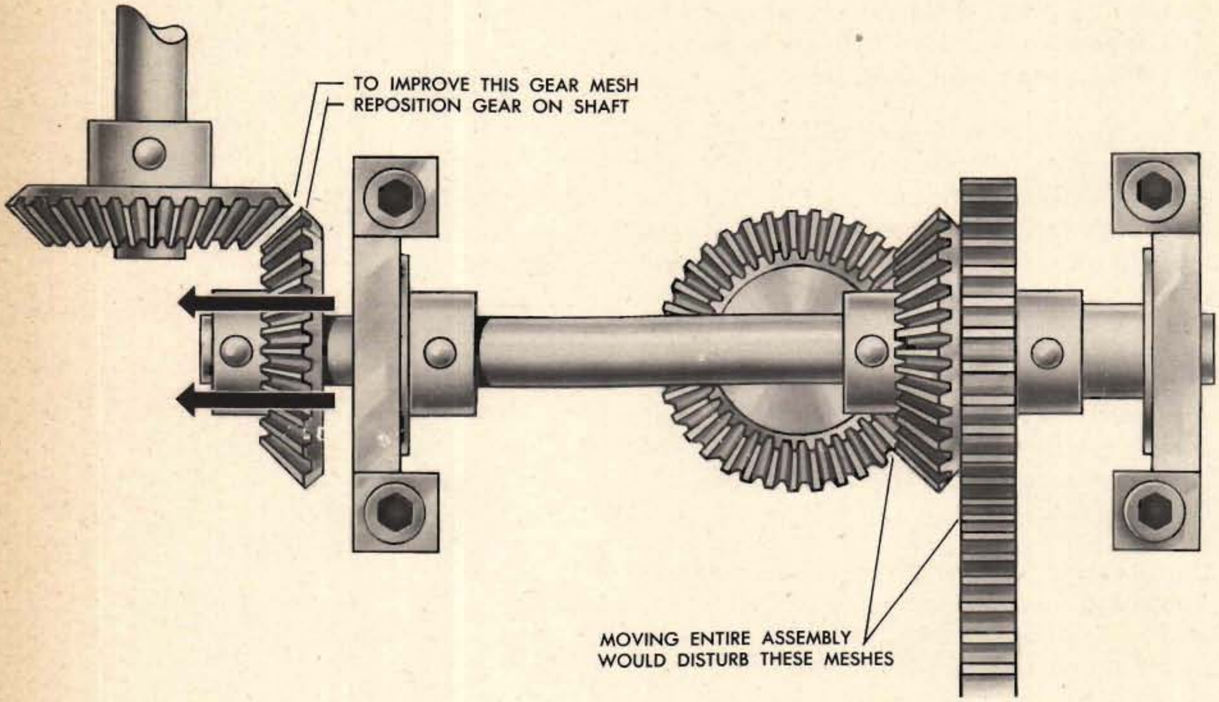








Repositioning a gear on a shaft

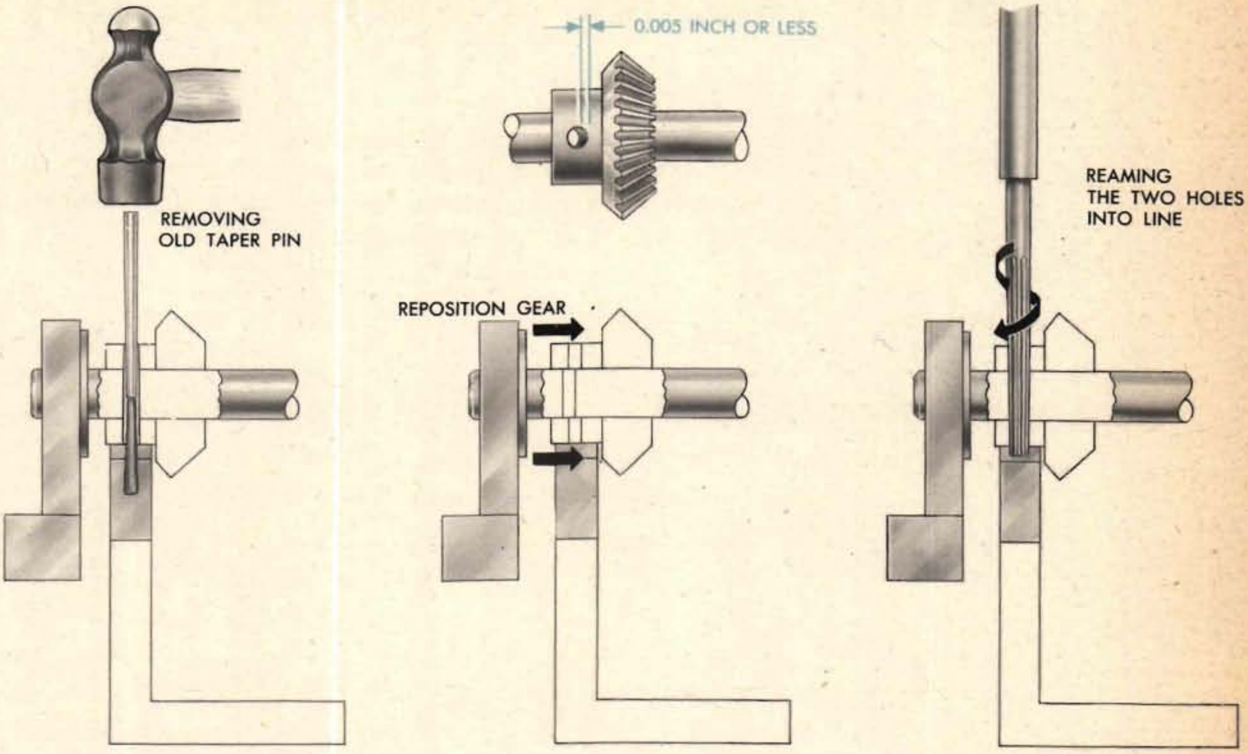


Sometimes the best method of repositioning a gear is to unpin the gear and move it into a new position. This operation is often necessary to obtain a correct bevel gear mesh on an assembly which has two or more bevel gears. If the whole assembly is moved to reposition one bevel gear, the other bevel gear meshes may be disturbed.

In relocating a gear to correct the mesh, it is best to use new parts if they are available.

If new parts are not available, an oversize taper pin must be used with either the old shaft or a new one. If the gear does not have to be moved more than 0.005 inch, the old shaft may be used. But if it must be moved more than 0.005 inch, a new shaft should be used. The use of oversize taper pins should be avoided, if possible, because it requires reaming a larger hole which will weaken the assembly.

Using the same shaft



First remove the taper pin by carefully tapping it out from the small end. After repositioning the gear, insert and tighten a set screw to hold the gear. Be sure to keep the large end of the hole in the hub over the large end of the hole in the shaft.

Hand-ream the two holes into line, seat an oversize taper pin, and stake it.

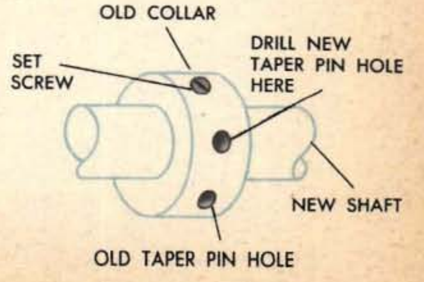
Check the shaft for run-out and *remove the set screw* before reinstalling the assembly.

Using a new shaft

Fit the gear and other parts to the new shaft, and reinstall the assembly in the instrument to correct end play and lost motion. Position all the parts and hold them in place with set screws. Then remove the assembly for pinning.

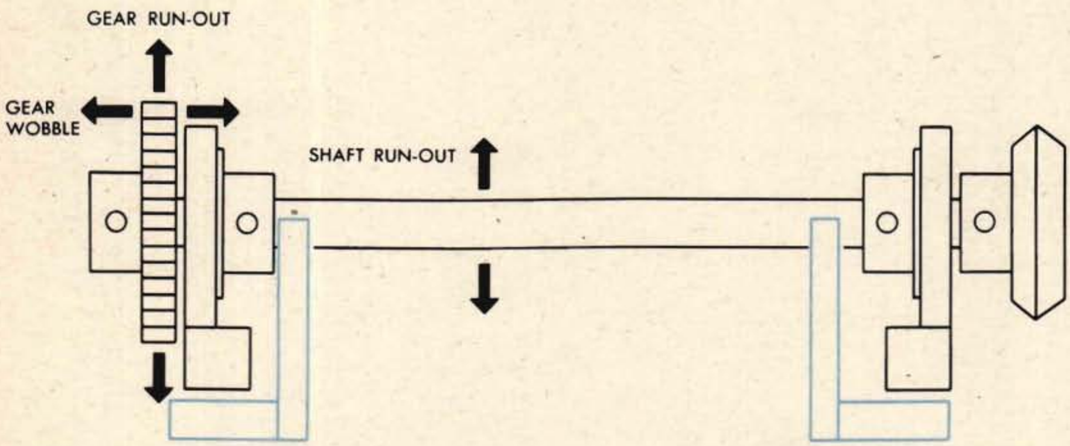
When the same collar or hub is used, the simplest method is to drill an entirely new hole for the taper pin. Use a straight drill and a hand reamer as explained on page 63.

After pinning the parts, check the shaft for run-out and *remove all set screws* before reinstalling the assembly.



Bench checking a shaft assembly

Whenever a shaft assembly has been removed from an instrument for any repair, it should be checked for shaft run-out, and for gear run-out and side wobble. Gear run-out and side wobble are almost always caused by a bent shaft.

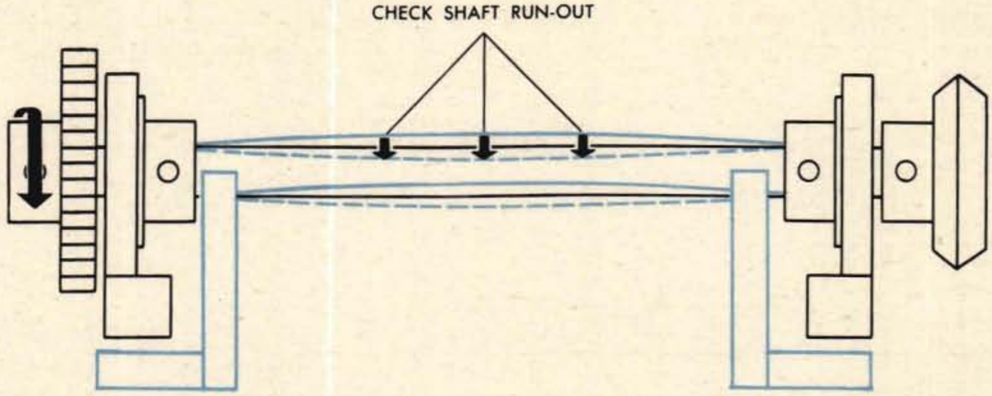


When any part has been newly pinned, checking the shaft for run-out is especially important.

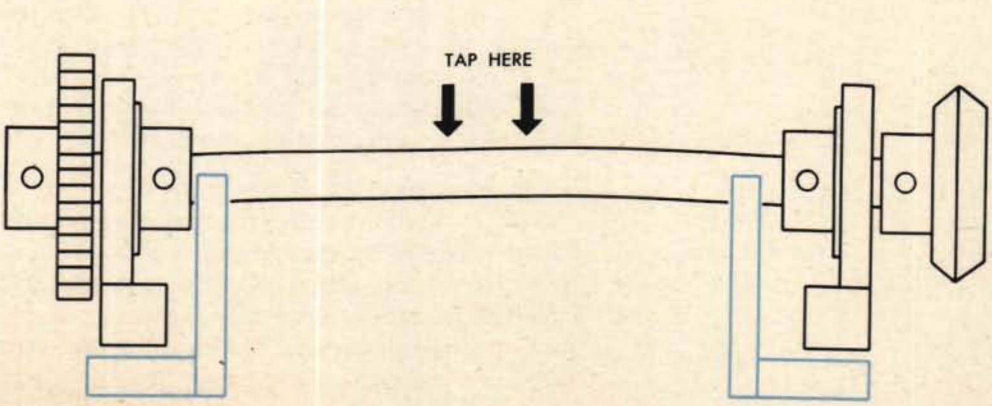
Place the entire assembly on V rests or pinning supports on a bench plate. A dial indicator mounted on the plate alongside the assembly is used to make all measurements.

Shaft run-out

Mount the assembly with the V rests or pinning supports between the hangers, near the collars. Place the point of the dial indicator against the side of the shaft between the hangers and slowly turn the shaft. If the shaft runs out, the movement of the dial hand will indicate the exact amount. Repeat this check at several points on the shaft between the hangers.



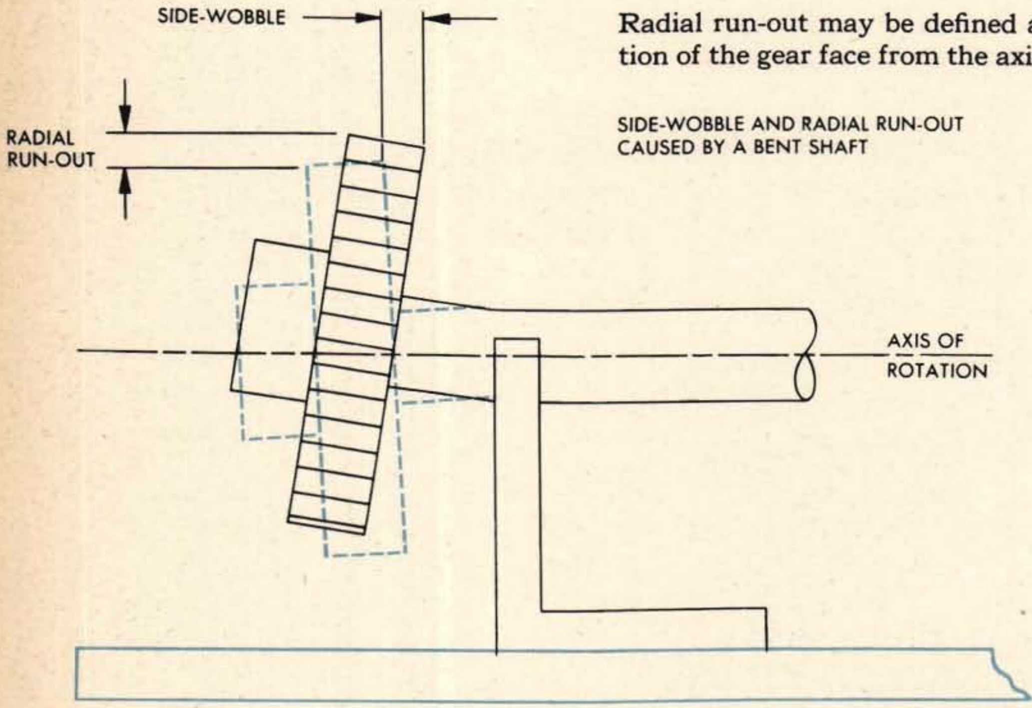
If a shaft does not run true within 0.002 inch total indicator reading at all points, it must be straightened. Strike the high points lightly with a plastic or soft-face hammer until the shaft is straight within this tolerance.



Gear side-wobble

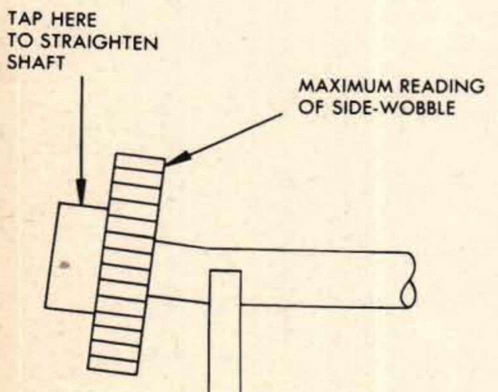
Side-wobble may be defined as the deviation of the side of a gear from a plane perpendicular to the axis of rotation.

Radial run-out may be defined as the deviation of the gear face from the axis of rotation.



SIDE-WOBBLE AND RADIAL RUN-OUT CAUSED BY A BENT SHAFT

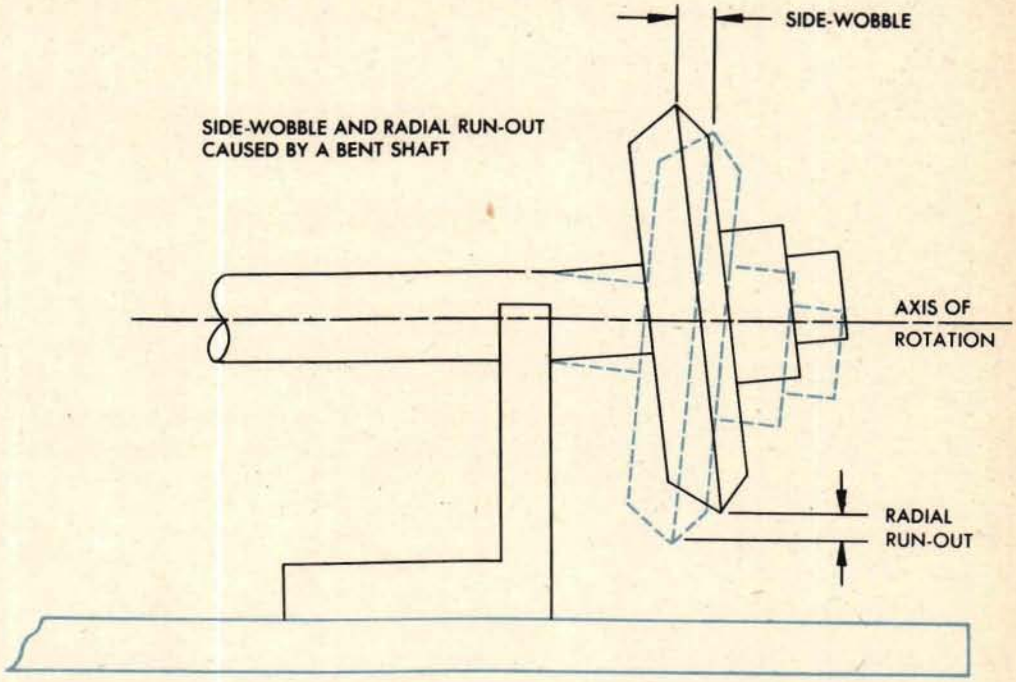
A bent shaft may cause side-wobble alone, or a combination of side-wobble and radial run-out in the same gear. Straightening the shaft to eliminate side-wobble will also eliminate radial run-out. For this reason, it is necessary to measure only side-wobble.



Radial run-out due to eccentricity need not be considered, because it is purely a manufacturing problem. If it exists after side-wobble has been eliminated, the parts of the assembly should be checked against the drawings.

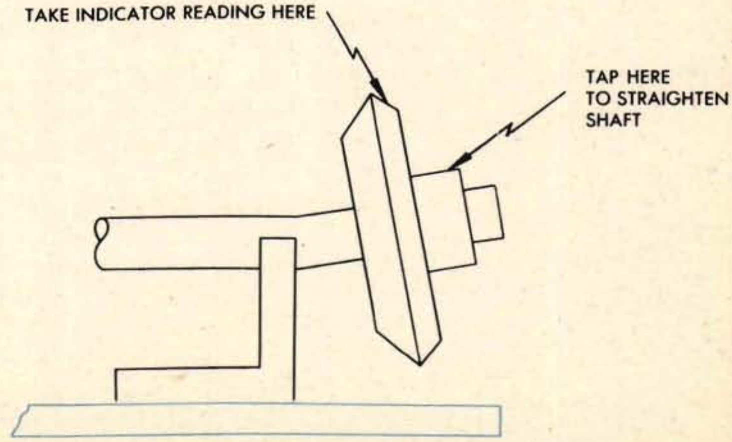
To measure side-wobble in a spur gear, place the point of the dial indicator on the side of the gear at the root of the teeth and turn the gear. The total indicator reading must not exceed 0.002 inch. If the reading is over 0.002 inch, straighten the shaft by tapping the gear hub until the gear runs true within this tolerance. CAUTION: Support the shaft in V blocks before hammering on it. Be careful not to damage the bearings.

Bevel gear run-out and side-wobble



Bevel gear side-wobble and run-out due to a bent shaft are measured simultaneously in one operation by placing the point of a dial indicator against the back of the gear at the root of the teeth and turning the gear.

Since the backs of bevel gears are cut at an angle, the total indicator reading represents a combination of side-wobble and run-out. If it exceeds 0.001 inch, straighten the shaft by tapping the gear hub until the gear runs true within this tolerance.



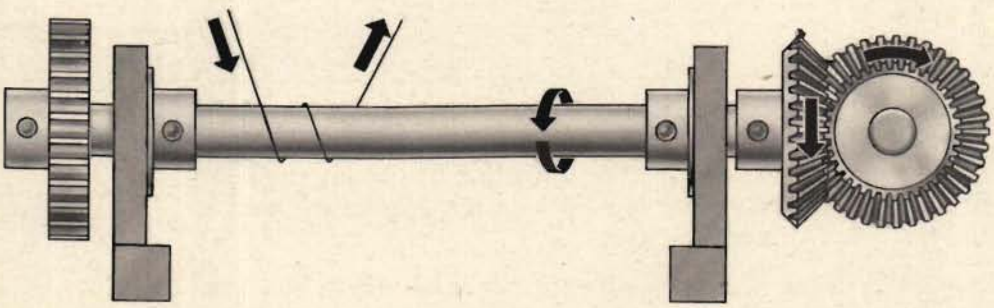
Final mounting of a shaft assembly

Locate the assembly on the plate over the screw holes. Insert the screws and tighten them enough to hold the assembly while it is checked in place.

Checking an assembly in place

Check the assembly for end play and for lost motion at the gear meshes. Obtain the correct position by loosening the screws and shifting the hangers toward or away from the meshing gears if necessary.

If there are tight spots in a mesh, inspect the gear teeth for burrs or nicks. If any are found, carefully remove them with a jeweler's file.



Running-in

Slight stickiness or roughness in a gear mesh can often be eliminated by lubricating and running the gears for a short time. The shaft may be turned by means of spinning cord wound several times around the shaft. Keep the cord near a bearing in order not to bend the shaft.

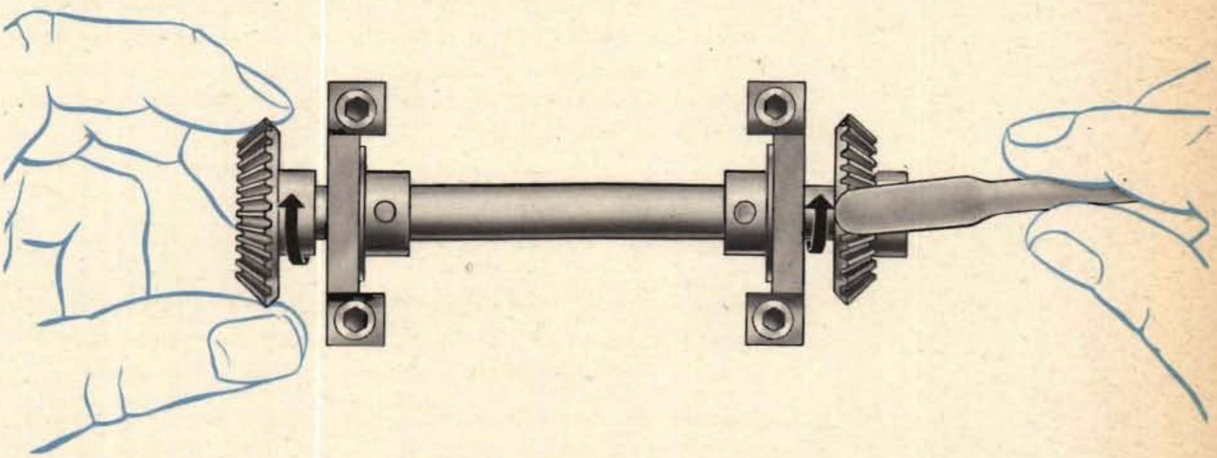
If running-in the gears with a lubricant does not make the mesh smooth enough, it may be necessary to use a running-in compound, but only as a last resort. Never use a commercial abrasive compound for running-in aluminum gears, however, because an abrasive hard enough to cut will become embedded in the aluminum. Embedded abrasive will wear the gear teeth excessively, and may eventually cause them to break off.

Making and applying running-in compound

The most suitable base for a running-in compound is rottenstone, but even the finest grade obtainable should be sifted through a 230-mesh screen.

To make a running-in compound suitable for use on instrument gears, mix light machine oil with the screened rottenstone to about the consistency of heavy cream.

Apply only a small amount, uniformly. Soft wood applicators or brushes with loose bristles should not be used because they may shed splinters or bristles in the compound.



This running-in or final fitting operation should be continued only long enough to obtain the desired smoothness of operation, and should be done slowly enough to prevent throwing the compound off into bearings or other mechanisms. As an added precaution, protect nearby mechanisms by covering them with tissue. Afterward, wash the shaft assembly thoroughly. Pay particular attention to cleaning the ball bearings.

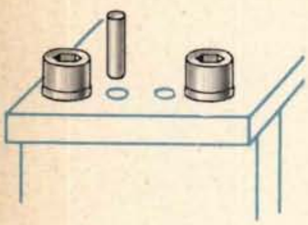
Washing and lubricating an assembly

After the final fitting is completed, wash the whole assembly thoroughly with a solvent equivalent to Navy Spec. 14K1 to remove all traces of compound and other foreign matter.

Finally, when the assembly is completely dry, lubricate all bearings and gears with a fine film of light oil.

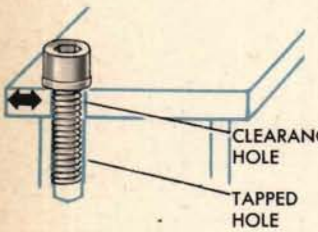
DOWELING

PARTS ARE POSITIONED BY DOWELS



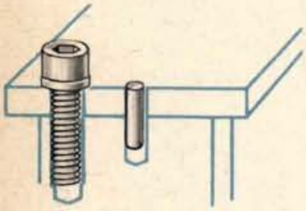
A dowel is a pin driven into matched holes in two parts of an assembly to hold them in position after they have been adjusted. Dowels eliminate shifting of screw-fastened parts and make it possible to reassemble them exactly in their original positions without further adjustment.

PARTS CAN SHIFT WHEN HELD BY SCREWS



In order to make screw-fastened parts easily interchangeable, clearance holes are drilled 0.005 to 0.010 inch larger than the outside diameter of the screws. Unless dowels are used to hold the parts in position, the parts may move through this clearance if they are subjected to a heavy load or shock, or if the screws become loose. This small movement is enough to bind gear meshes in an instrument.

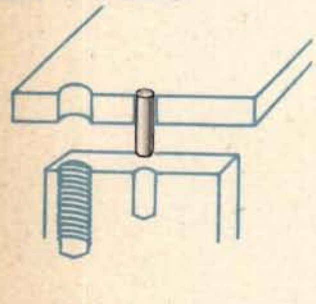
DOWELS PREVENT SHIFTING



Dowels should be fitted only *after the parts have been correctly aligned*. If it becomes necessary to re-align the parts after the dowels are fitted, the parts will have to be doweled again.

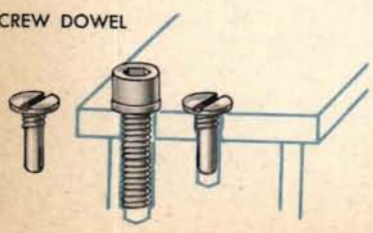
If dowels are not square with the parts they join, separating the parts will be extremely difficult. Therefore it is important in all doweling to drill every hole at right angles to the surfaces of the parts. Wherever possible, this should be done on a drill press.

THE PART IS LIFTED TO CLEAR THE DOWELS



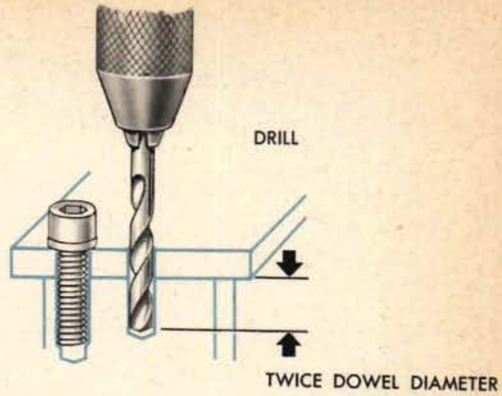
Dowel holes are drilled for a drive-fit in the smaller of the parts to be doweled, usually the one provided with screw clearance holes, and for a push-fit in the larger part. When the screws are removed and the parts separated, the dowels remain in the smaller part. To separate doweled parts, it is necessary to lift the smaller part straight up until the dowels clear the holes in the other part.

SCREW DOWEL



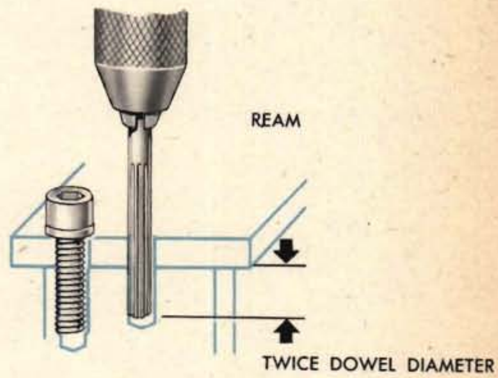
Where there is not enough space to lift a unit to clear the dowels, it is usually fastened with screws and held in position by *screw dowels*. Like other dowels, screw dowels are fitted only after the parts have been correctly aligned.

When the dowel holes are provided in one of the parts to be joined, they are used to guide the drill in making the matching holes in the other part. To make the new holes straight and to avoid enlarging the prepared hole, the drill must be held exactly perpendicular to the surface.

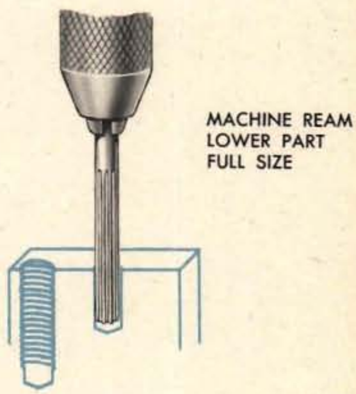


Dip the drill in grease to lubricate it and to make it retain chips. Drill each new hole to a depth twice the diameter of the dowel to be used in it.

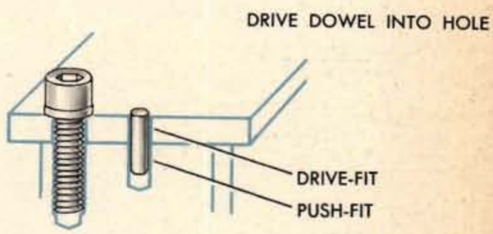
With an undersize reamer, ream through both parts to the bottom of the new hole. This operation will make a drive-fit in both parts, or a permanent fit.



Where the parts may have to be separated later, always remove the upper part and ream the lower part for a push-fit with a full-size reamer.

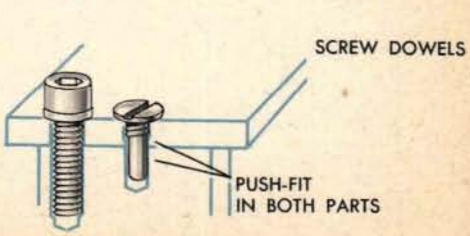


Grease the dowels before driving them.



Screw-dowel holes are reamed for a push-fit in both parts to allow the dowel to turn easily.

To redowel parts, remove the old dowels and fit larger ones, or drill a new dowel hole near the old one.



RIVETING

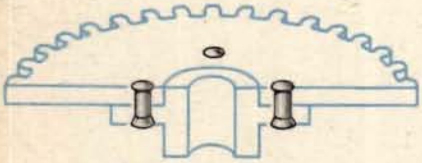
Riveting is a means of fastening two or more parts of an assembly together by forming or peening metal. Rivets may be used, or one of the parts may serve as a rivet in addition to its other functions in the assembly. Here are illustrations of both types of riveted assembly.

In the first, rivets have been fitted in matched holes drilled through a gear and the flange of a gear hub.

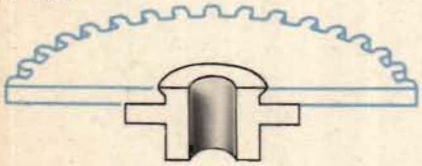
In the other type, a lip on a hub has been peened over into a countersink in a gear.

Instructions for both methods of riveting follow. When either method is used, the parts must be held tightly together during the operation to prevent spreading them. To avoid bending a part, it is necessary to provide support directly under the work, where the force of the hammer blows is concentrated. No hammer blow should ever strike a finished surface.

WHERE RIVETS ARE USED



WHERE ONE OF THE PARTS SERVES AS A RIVET



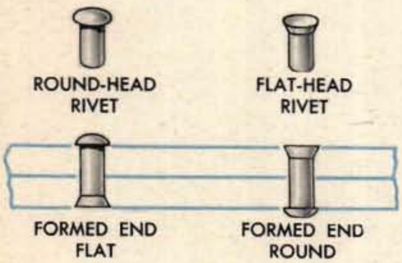
Where rivets are used

The most commonly used rivets are the *round-head* and *flat-head* types. A *round end* or a *flat end* can be formed on either type of rivet.

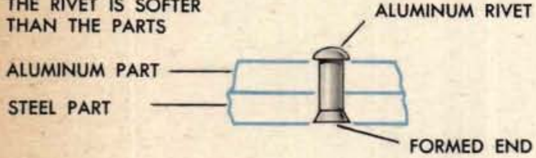
All rivets used in an instrument are of soft steel or aluminum, and they are worked cold. When two parts of different materials are to be riveted together, the head of the rivet is formed against the harder of the two parts.

To prevent shifting of the clamped parts during riveting, always insert all the rivets before starting to form the ends. Be sure that all of them fit snugly in the holes, but never force a rivet into a hole, because forcing it may spread the parts. If any of the holes are out of line, use a drill of the proper size in a hand-chuck to align them.

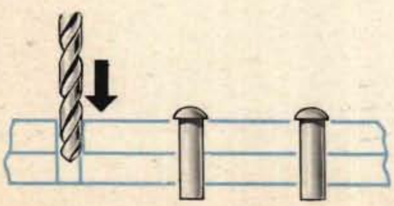
RIVET ENDS

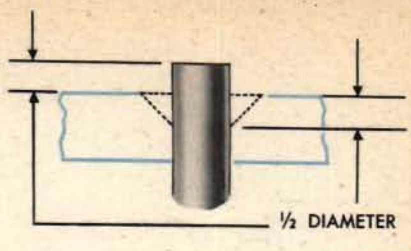


THE RIVET IS SOFTER THAN THE PARTS



ALIGNING RIVET HOLES

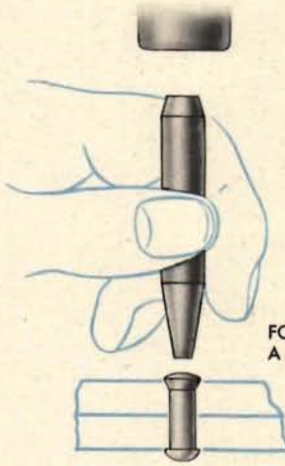




The depth of the countersink in which a flat end is formed should be about half the diameter of the rivet. Select a rivet which projects above the surface of the part to a height equal to the depth of the countersink.

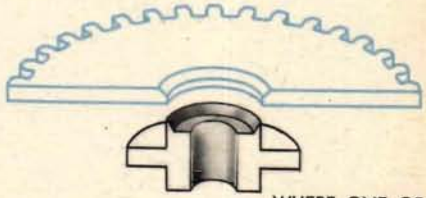
Form the end by light blows with a flat-point punch and a hammer. Many light blows will form a better rivet end than a few heavy blows. After the end is evenly formed in the countersink, file the excess material until the rivet is flush with the surface of the part.

Form a round end above the surface of the part by using a cup-point punch instead of a flat-point punch.


FORMING A FLAT END

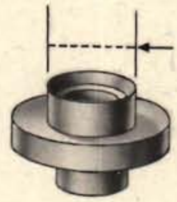
Where one of the parts serves as a rivet

The parts are specially prepared when one of them serves as a rivet. One part is provided with a raised lip to be peened over into a prepared countersink in the other. The part which is peened over resembles a flat-end rivet in this respect.


WHERE ONE OF THE PARTS SERVES AS A RIVET

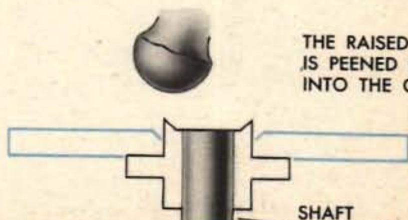
The instructions on assembly drawings sometimes refer to this operation as spinning. Spinning requires power machinery and special fixtures to force the lip into the countersink with pressure rollers. But any part made for spinning can be peened by hand on the bench with a hammer. Where one part drives another, as in a hub-and-gear assembly, dowels must be fitted to prevent slipping of the parts.

Before peening the lip over, measure the diameter of that part of the hub which fits into the gear. On the next page instructions are given for making a special jig to center the dowel holes on this diameter.

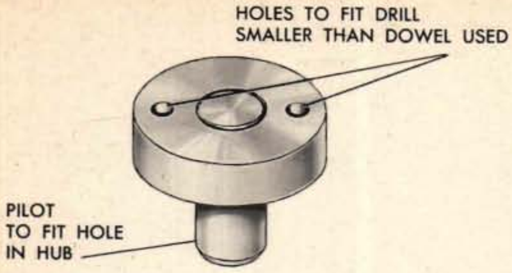


While peening the lip over, keep a short length of shaft in the hole to prevent distortion of the hub. Peen the raised lip over into the countersink as uniformly as possible by tapping very lightly all around the edge.

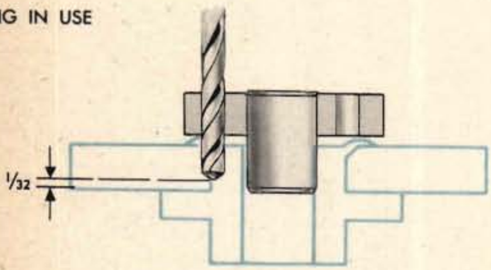
Now dowel holes must be drilled.



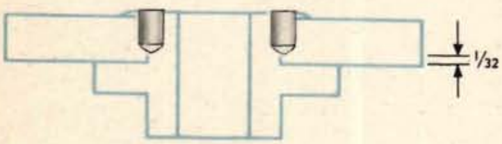
A JIG



THE JIG IN USE



DOWELS IN POSITION



The two dowel holes must be drilled half in the hub and half in the gear to prevent slipping. A special jig to fit each assembly must be made to center these holes accurately and to keep the drill from walking away from the harder of the two metals.

Model the jig on the drawing shown here. It consists of a drill plate and a pilot which fits into the hub hole to center the jig on the assembly.

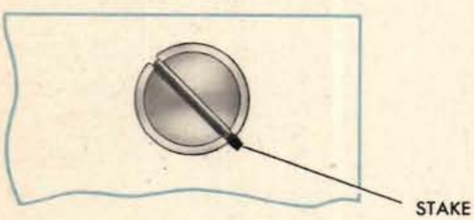
On the drill plate, center the holes the same distance apart as the previously measured diameter of the hub where it fits into the gear. Drill these holes slightly smaller than the dowels to be used.

Using the jig, drill two holes in the hub-and-gear assembly to a depth 1/32 inch less than the gear thickness. Finally, drive two dowels in the holes and stake them with a center punch.

Riveting and positioning eccentric roller studs

A RIVETED ECCENTRIC STUD

THE STUD IS STAKED



This operation is a variation of riveting where one of the parts serves as a rivet.

Fit the stud in the hole. If necessary, ream the hole for a tight push-fit. Before peening the lip, remove the stud and grease it.

Tapping lightly with a hammer, peen the lip evenly and turn it occasionally until it is fairly hard to turn. The stud and the part will now hold together, but the stud can still be positioned.

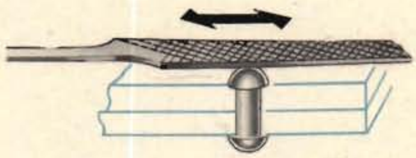
To position the stud, insert a screwdriver in the slot and turn the stud to the correct position.

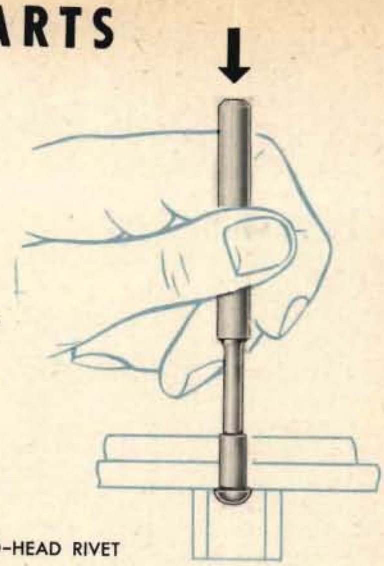
After this final adjustment, lock the stud by staking or forcing metal into one end of the slot with a center punch.

SEPARATING RIVETED PARTS

Where rivets are used

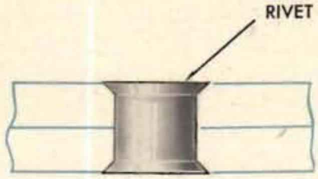
To remove a rivet with a round end, file off the formed end and drive out the rivet with a punch.

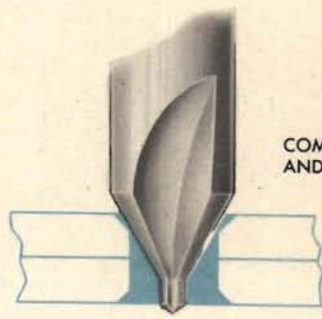




REMOVING A ROUND-HEAD RIVET

In removing a rivet with a flat end, the formed end is drilled out with a center drill. To avoid damaging the countersink, be very careful to center the drill accurately in the rivet.

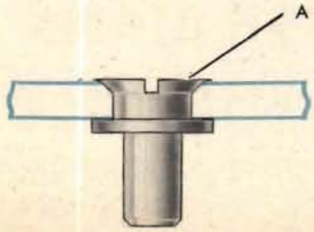


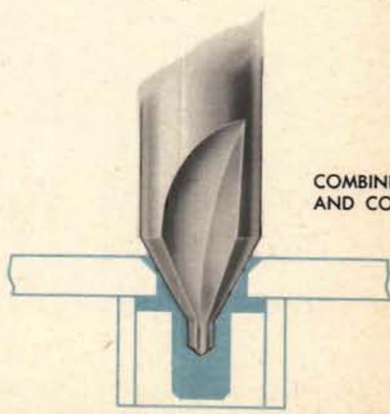


DRILLING OUT A COUNTERSUNK RIVET

Where one of the parts serves as a rivet

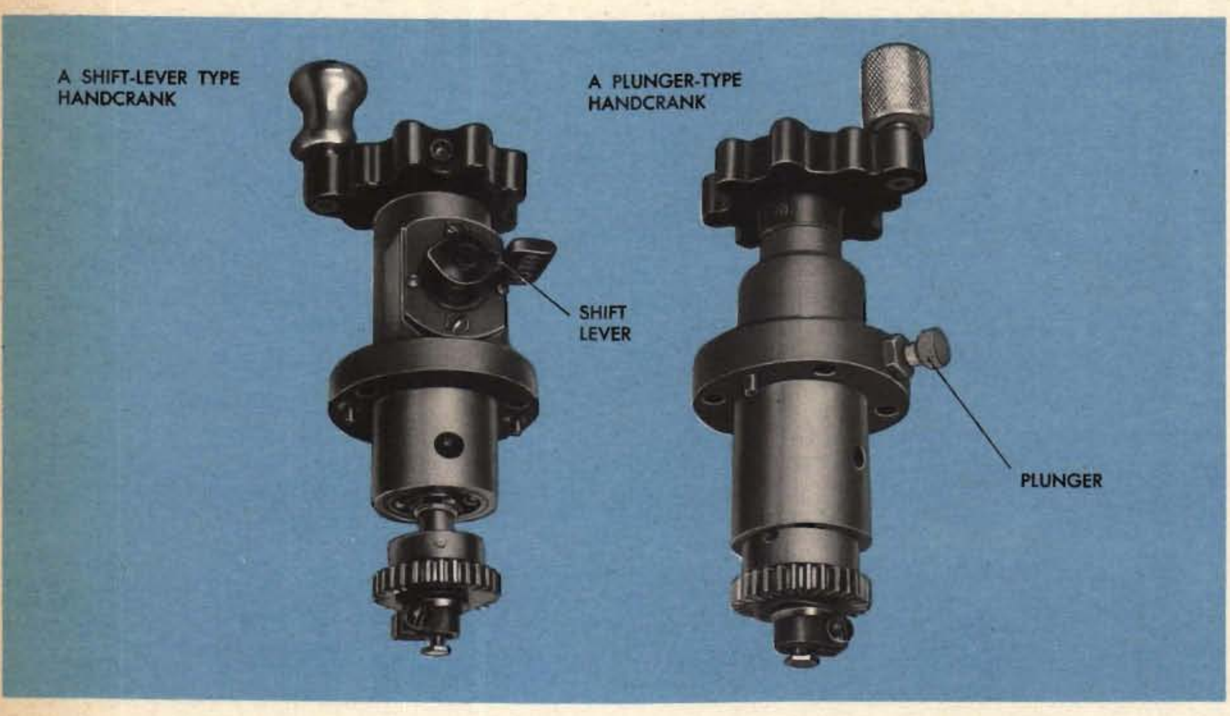
To separate two riveted parts where one of the parts serves as a rivet, drill out the peened metal with a center drill. Be careful to center the drill accurately. The drilled part which has served as a rivet must be replaced, but the part with the countersink may be used again.





DRILLING OUT A STUD

HANDCRANKS



There are several types of handcranks. The simplest is a one-position handcrank with the drive gear pinned to the shaft. The others are the two- and three-position types, with holding and safety frictions.

The most common type, the two-position handcrank with either a plunger or a shift lever, and with both a holding and a safety friction, is discussed in detail in this chapter.

A handcrank may shift with difficulty or bind when turned if the cover on which it is mounted is improperly seated. This possibility should be investigated before an apparently faulty handcrank is removed from the instrument.

A handcrank can be removed by taking out the screws which hold the adapter to the cover. Usually the handcrank must be removed in order to locate the trouble.

Typical symptoms

JAMMING: The handcrank will not turn, or it cannot be shifted.

STICKING: The handcrank sticks or binds intermittently, or moves stiffly.

SLIPPING: Turning the handcrank will not turn the drive gear; or the handcrank loses its holding power.

Locating the cause

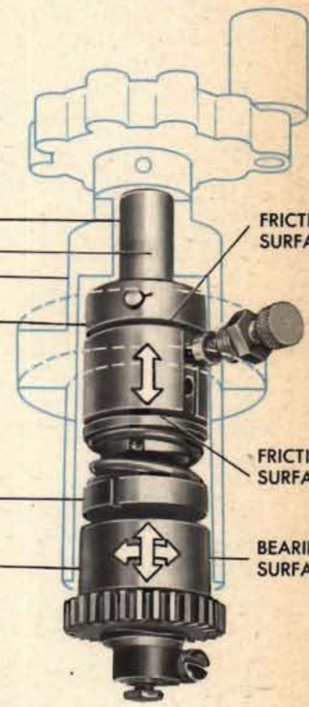
Shaft: jamming and sticking

A handcrank shaft may jam or stick because of a frozen holding friction, metal chips between the shaft and adapter, a bent or burred shaft, a sticking shift lever, or bent plunger.

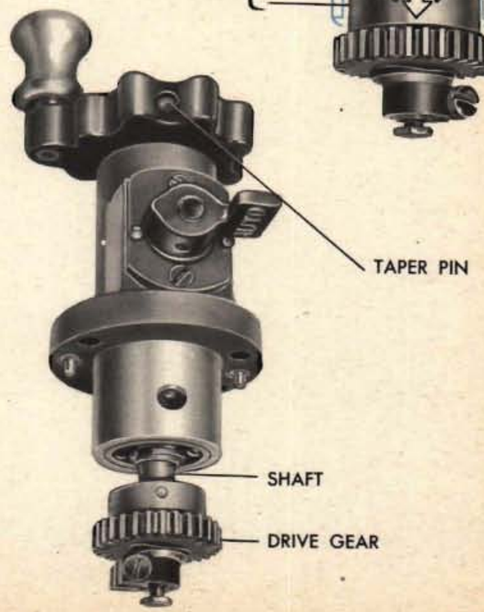
In a plunger-type handcrank, if the bushing of the holding friction freezes to the shaft, remove the handcrank assembly from the adapter, loosen the adjusting nut, and try to free the bushing so that it will turn on the shaft. If it remains frozen, remove the friction from the handcrank and inspect the shaft and bushing for dirt or damage.

If the shaft of a plunger-type handcrank is frozen in the adapter, try to free it by turning the knob. If it will not turn freely, remove the handcrank from the adapter and inspect the shaft and adapter for dirt or burrs.

If the shaft sticks or jams but none of the above causes are found, inspect all moving parts and the inside surfaces of the adapter for metal chips and dirt.

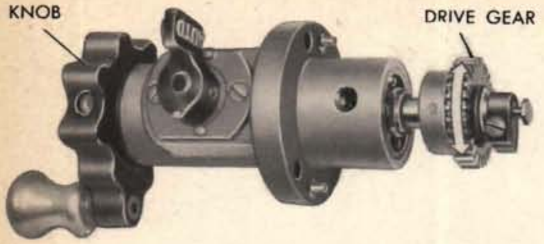


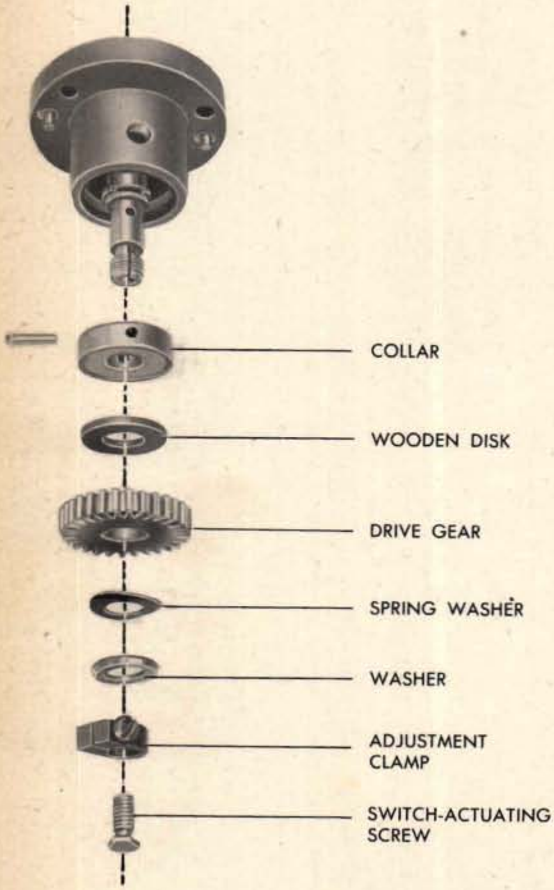
Drive-gear wobble usually indicates a bent handcrank shaft. Complete disassembly is necessary in order to straighten or replace a shaft.

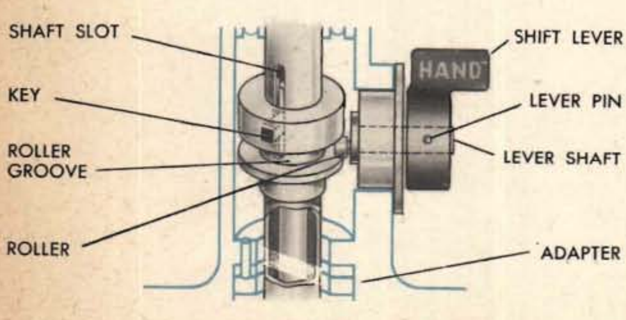


Shaft: slipping

Slipping of the shaft with respect to the knob indicates that the taper pin is missing. When replacing a taper pin in a knob, be sure to stake it securely.







Safety friction: jamming and sticking

If the drive gear is frozen to the shaft, the safety friction will jam instead of slipping when a limit is reached. To free the drive gear, hold the knob and try to turn the drive gear by hand. If the gear cannot be turned, it should be disassembled for cleaning or repair.

Safety friction: slipping

Slipping of the drive gear under normal load when the handcrank is being turned may be caused by improper adjustment or a damaged spring washer.

If the clamp cannot be screwed down far enough to compress the spring washer, inspect the threads on the shaft for nicks or dirt. Dirt or small nicks can be removed from the threads on the end of the shaft without completely disassembling the unit. Badly damaged threads require replacement of the clamp or shaft, or both. Complete disassembly of the handcrank is necessary in order to replace a shaft.

Shift lever: jamming and sticking

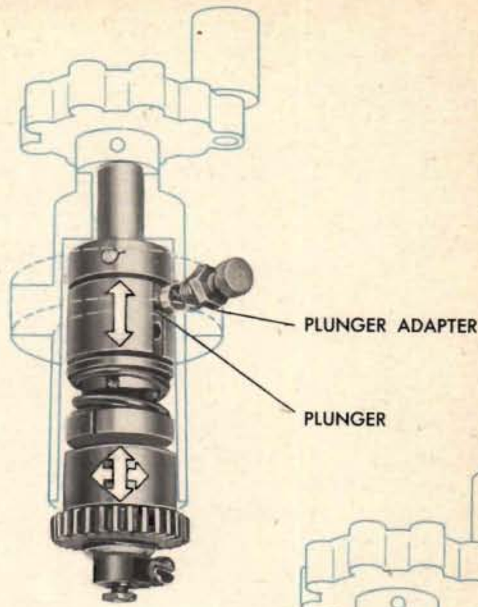
If a lever-type handcrank is difficult to shift or will not shift at all, look for a bent lever shaft; a dirty or damaged roller, roller groove, or shaft slot; dirt or metal chips between the moving parts and the adapter; or a bent key. If turning the shift lever does not shift the handcrank, look for a sheared or missing taper pin. In order to clean, repair or replace these parts, partial disassembly of the handcrank is necessary.

Shift lever: excessive lost motion

Excessive lost motion between the shift lever and handcrank is usually caused by a badly worn roller or roller groove, or both. Replacement of such worn parts requires partial disassembly of the handcrank.

Plunger: jamming and sticking

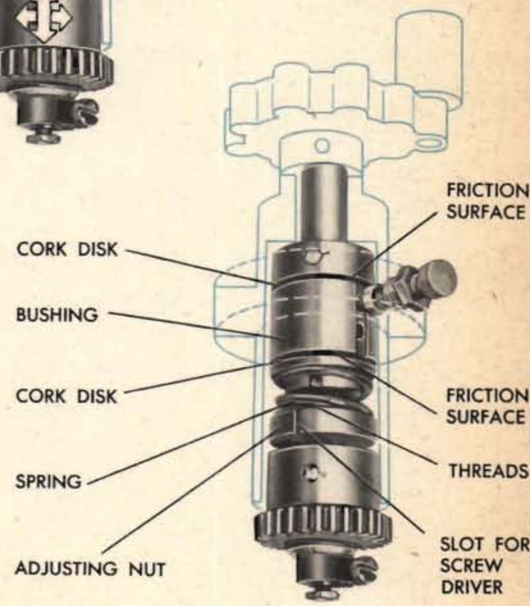
If a plunger is difficult to operate, it may be bent, or there may be foreign matter between the plunger and its adapter.



At least partial disassembly is necessary in order to straighten or replace the plunger, or to clean the inside of the adapter and the handcrank surfaces near it.

Holding friction: slipping

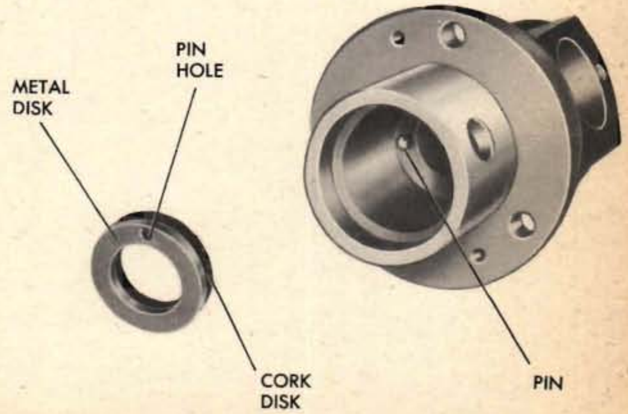
If the quantity which is supposed to be held backs out of the handcrank, the holding friction is slipping. Slipping may result from improper adjustment, a damaged spring, or a glazed cork disk.



If the spring is damaged, the friction cannot be adjusted so that it will hold.

If the cork disk has become glazed or damaged, it must be replaced. Partial disassembly of the unit is necessary in order to replace a disk. See the instructions for attaching cork to metal, page 18.

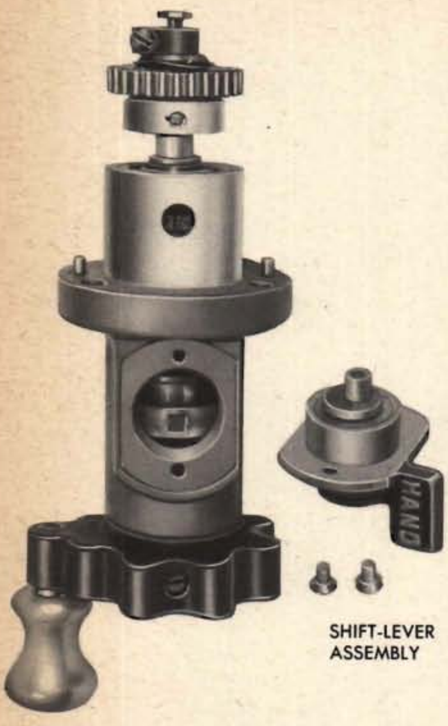
Damaged or dirty threads in the adjusting nut or on the shaft, or burrs on the edge of the nut slot prevent proper adjustment of the nut. Parts with damaged threads should be replaced. Burred surfaces may sometimes be smoothed.



In a shift-lever handcrank, failure of the friction to hold may also be caused by the metal disk not being seated properly on the pin in the adapter or by a missing pin.

Disassembling the unit

In removing a handcrank, try not to damage the paper gasket which separates the adapter from the cover.

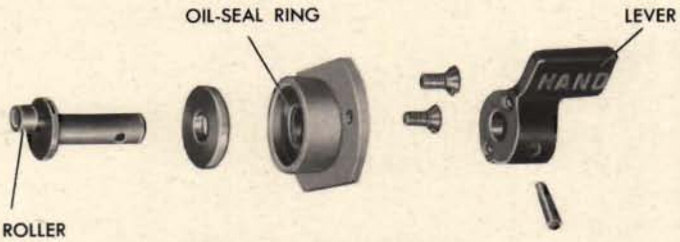


Disassembling the shift-lever type

1 Remove the two screws and carefully lift out the shift-lever assembly. Do not lose the roller.

2 Drive the taper pin out of the lever and separate the parts. Do not remove the oil-seal ring unless it must be replaced.

If the oil-seal ring is damaged, remove it by the same method used to remove a bearing.

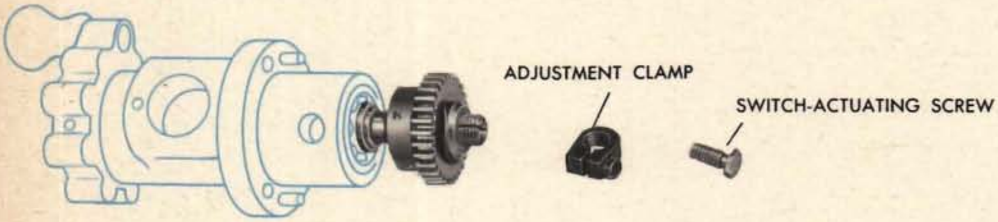


SHIFT-LEVER ASSEMBLY DISASSEMBLED

3 Loosen the adjustment clamp.

4 Carefully unscrew the switch-actuating screw.

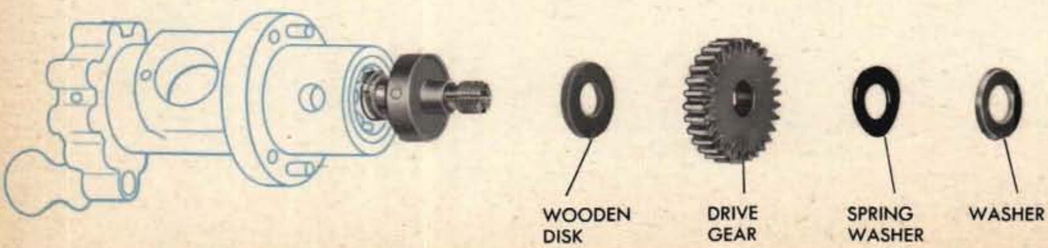
5 Unscrew the adjustment clamp from the shaft.



6 Remove the plain washer and the spring washer from the shaft.

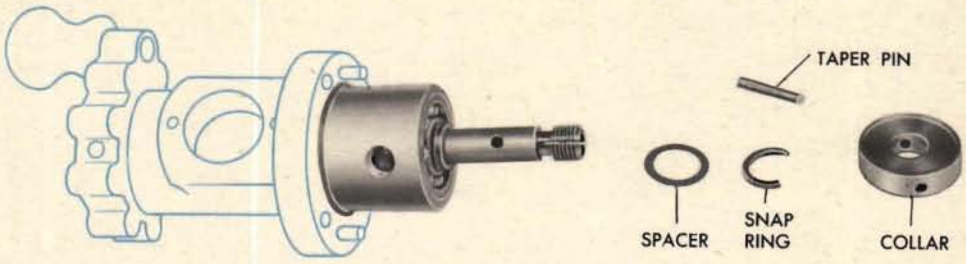
7 Slide the drive gear off the shaft.

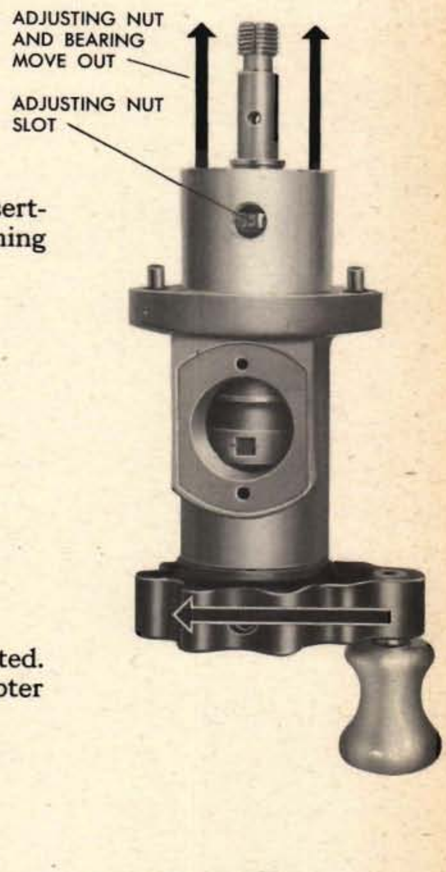
8 Remove the wooden disk from its recess in the collar.



9 Drive the taper pin out of the collar and remove the collar from the shaft.

10 Carefully remove the snap ring and spacer.



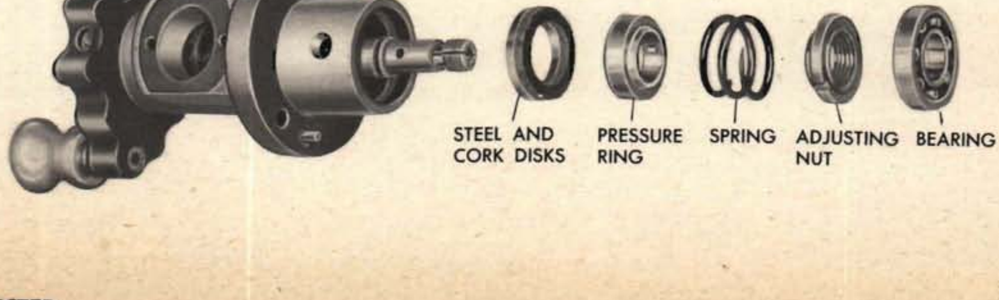


11 Remove the bearing and the adjusting nut by inserting a screw driver in the slot of the nut and turning the handcrank.

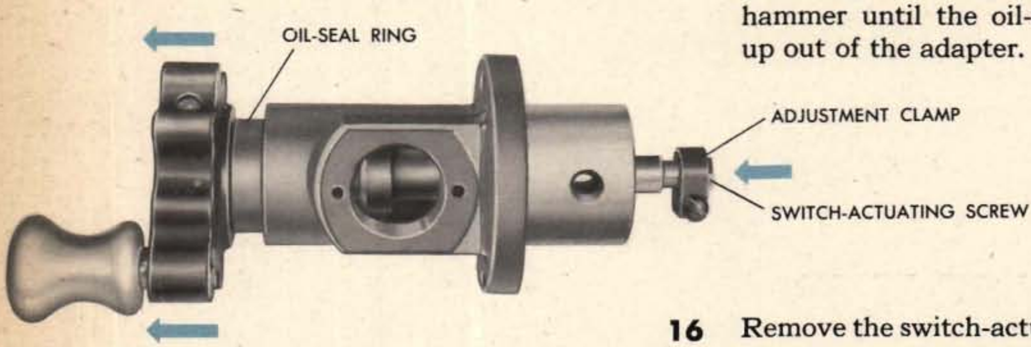
12 Take the spring off the shaft.

13 Slide the pressure ring down and off the shaft.

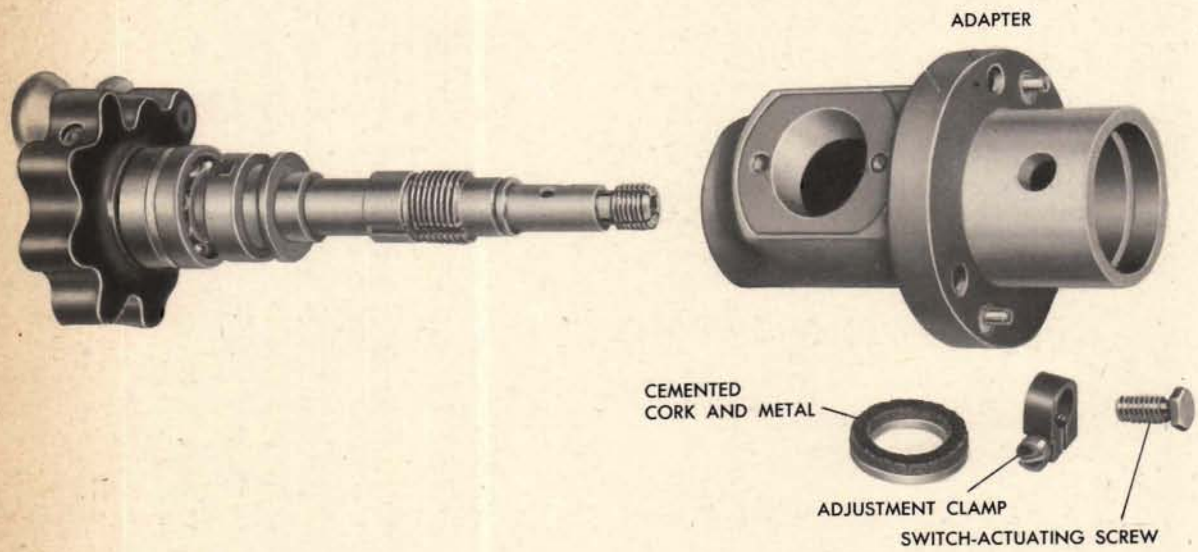
14 Remove the steel disk to which the cork is cemented. If it does not come out when the bottom of the adapter is tapped, it will when the shaft is removed.



15 Replace the adjustment clamp on the threaded shaft. Screw the switch-actuating screw in as far as it will go and tighten the clamp. Now tap the switch-actuating screw lightly with a plastic hammer until the oil-seal ring moves up out of the adapter.



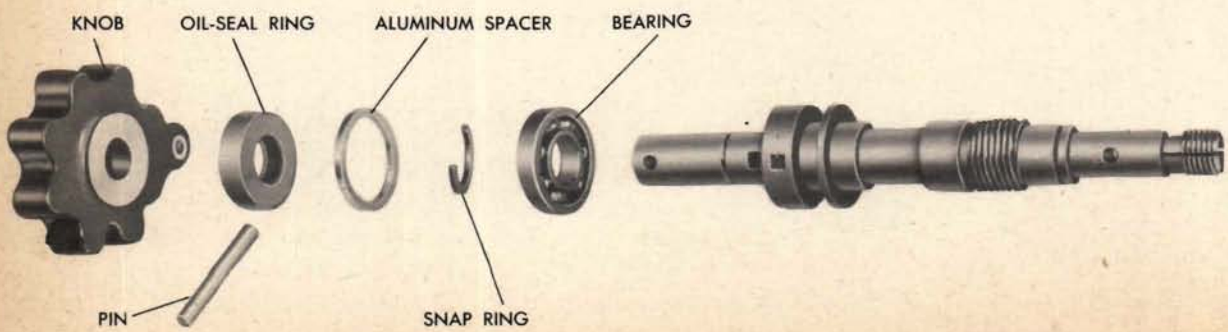
16 Remove the switch-actuating screw and the clamp and then lift the rest of the assembly out of the adapter.



17 Drive out the taper pin and lift off the knob. Polish the end of the shaft to remove burrs.

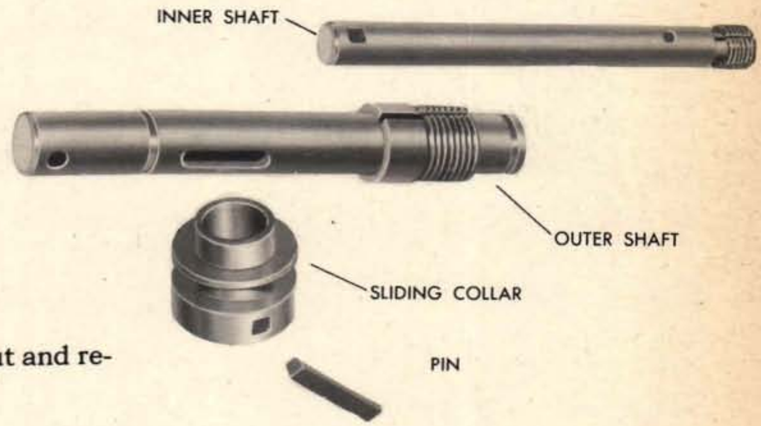
18 Slide the oil-seal ring off the shaft.

19 Remove the aluminum spacer, the snap ring, and the ball bearing.



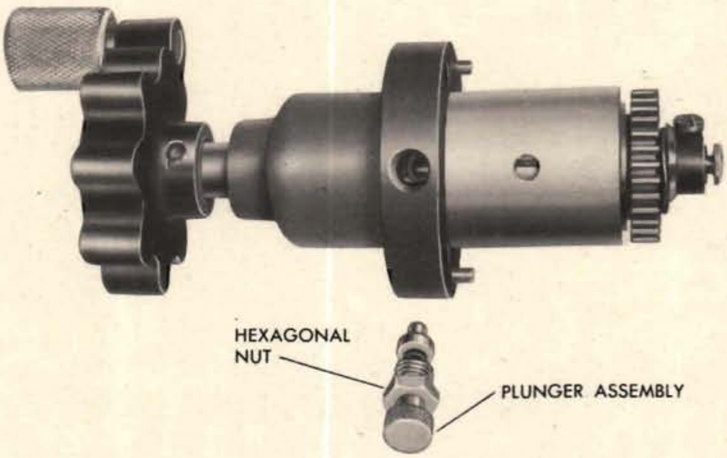
20 To separate the two shafts, drive the square pin out of the sliding collar. Remove the sliding collar.

21 Separate the two shafts.



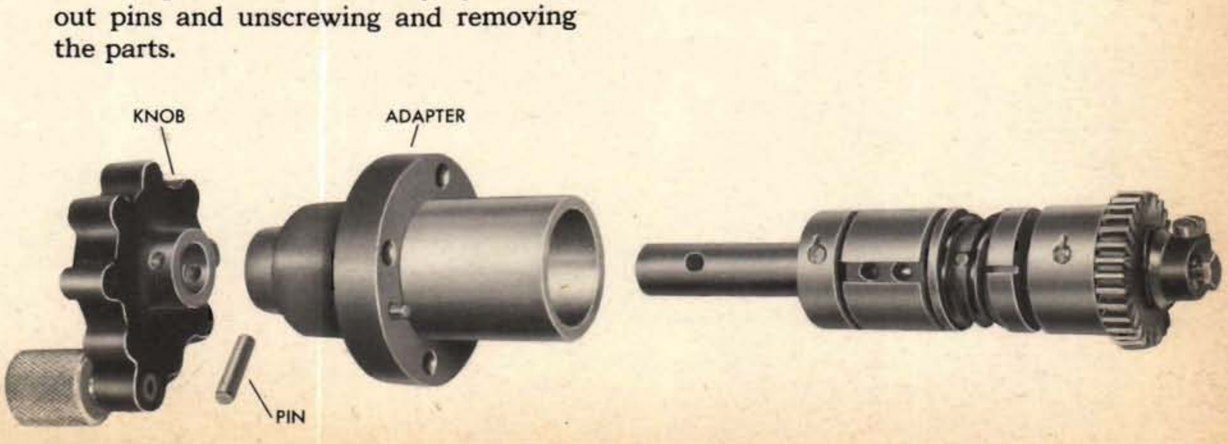
Disassembling the plunger type

1 Unscrew the small hexagonal nut and remove the plunger.



2 Drive the taper pin out of the knob.

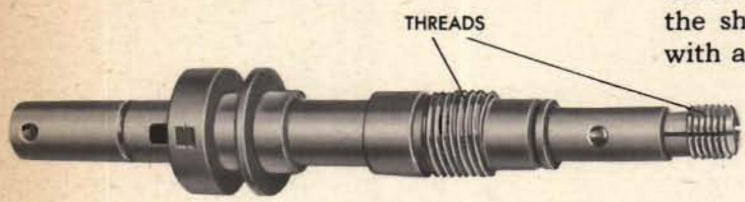
3 Remove the assembly from the adapter and complete the disassembly by driving out pins and unscrewing and removing the parts.



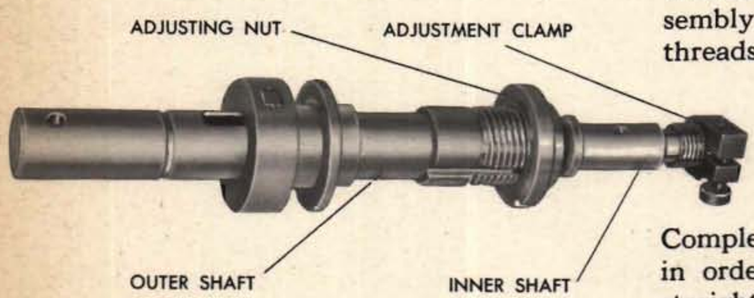
Repairing the parts

Repairing a shaft

Inspect the shaft threads for dirt or damage. Slightly damaged threads may be cleaned and smoothed, but it is usually best to replace the shaft. Dirty threads should be cleaned with an approved solvent.



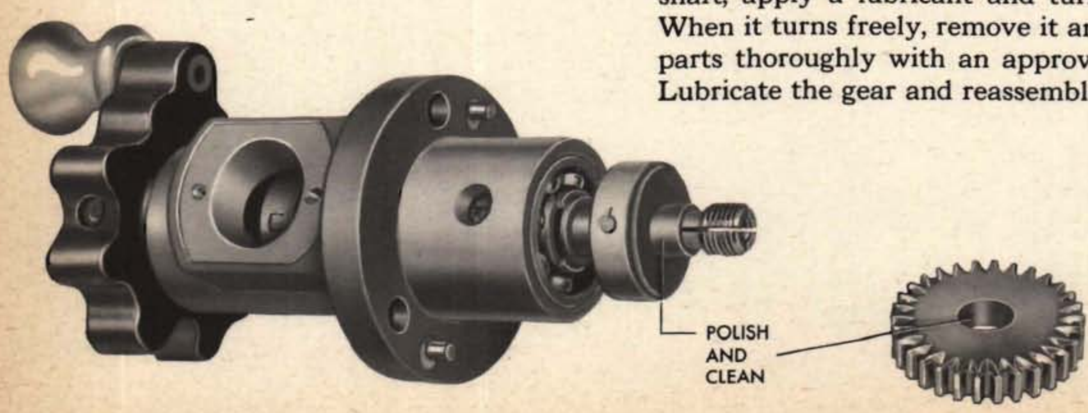
After cleaning or repairing the threads, lubricate them and turn the threaded clamp or adjusting nut back and forth over the threads until it moves smoothly. Only partial disassembly is necessary to clean or repair the threads.



Complete disassembly is usually necessary in order to straighten a bent shaft. After straightening a shaft, carefully smooth all burred surfaces. Then polish and clean the shaft before lubricating it.

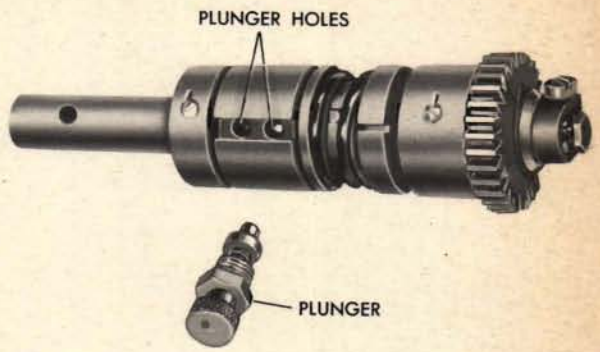
Repairing a drive gear

If a drive gear has frozen on its shaft, remove it. Inspect the inner surface of the hole and remove any burrs. Then polish the shaft and the surface of the hole in the gear. Clean these parts before reassembly. Fit the gear on the shaft, apply a lubricant and turn the gear. When it turns freely, remove it and clean all parts thoroughly with an approved solvent. Lubricate the gear and reassemble it.



Repairing a plunger

If a plunger is bent, remove it from the handcrank for straightening. Clean and polish its surfaces and check the inner end for excessive wear. Examine the plunger holes in the bushing for dirt or burrs. Polish, clean and lubricate these holes and the outer surfaces of the bushing. Lubricate the plunger and reassemble it.

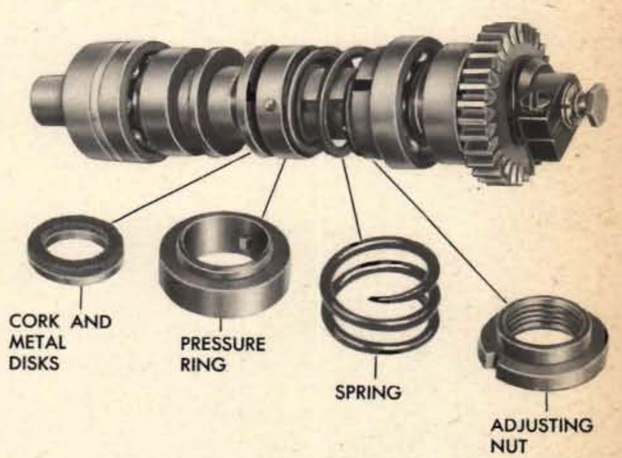


Cleaning a holding friction

Complete disassembly of the handcrank is usually necessary in order to clean a holding friction.

Separate the friction surfaces, thoroughly remove all grease, and clean the surfaces.

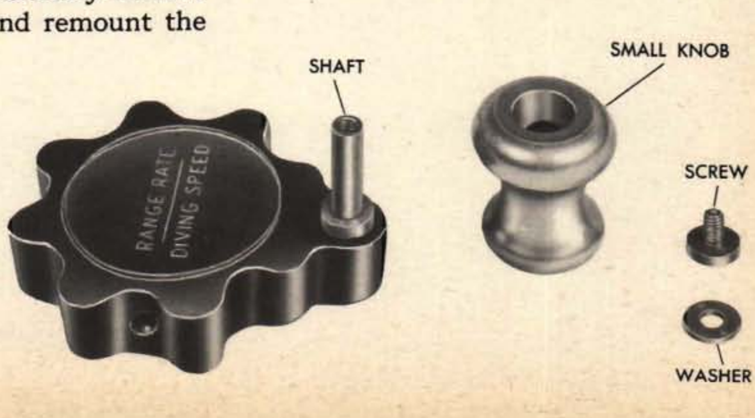
Clean and polish the outside surface of the adjusting nut and adjacent adapter surfaces so that the nut can be turned freely.



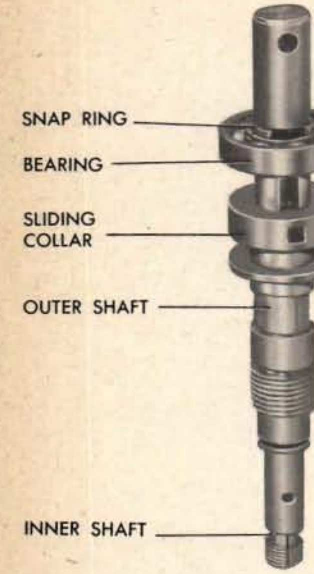
Repairing a knob

If the small knob will not revolve on its shaft, take it off by removing the screw in the top.

Clean and polish the shaft and the inside surface of the small knob. Examine these parts for burrs. If any are found, carefully remove them. Lubricate the shaft and remount the small knob on it.



Reassembling the unit



1 Slide the inner shaft into the outer shaft.

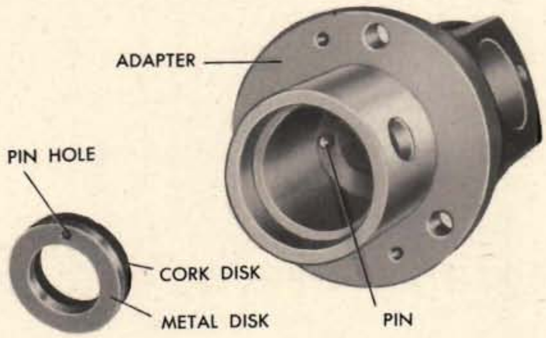
2 Replace the sliding collar on the outer shaft.

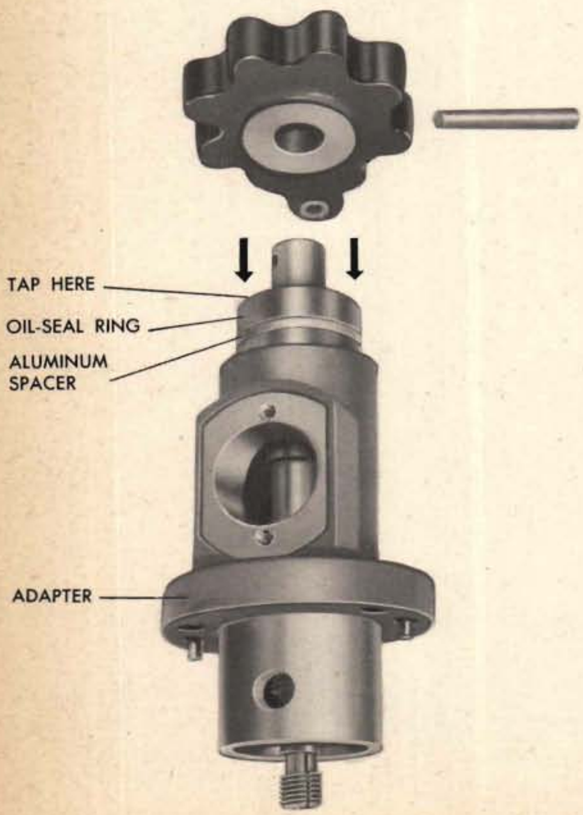
3 Pin the collar to the inner shaft with the square pin and stake the pin at both ends.

4 Replace the ball bearing and the snap ring on the outer shaft.

5 Slip on the aluminum spacer and then replace the oil-seal ring with its all-metal surface down.

6 Mount the cemented metal and cork disks in the bottom part of the adapter. Be sure to fit the adapter pin into the hole in the metal disk.





7 Lubricate the upper part of the handcrank assembly and mount it carefully in the adapter. Seat the oil-seal ring by tapping around its upper surface with a plastic hammer. In order to avoid damaging the shaft threads, support the adapter so that the end of the shaft is raised above the bench.

8 Pin the knob to the shaft.

9 Slide the pressure ring on the shaft with the broad friction surface toward the cork disk. The pressure ring is the ring with the key.

10 Replace the coil spring.

11 Screw the adjusting nut back on the shaft.

12 Replace the bearing on the shaft and seat it.

13 Replace the spacer (if required) and the snap ring.

14 Pin the collar to the shaft and replace the wooden disk.

15 Mount the drive gear with the beveled ends of the teeth up.

16 Replace the spring washer with its concave (hollow) side toward the drive gear.

17 Replace the beveled washer with its larger side down.

18 Replace the adjustment clamp on the threaded shaft.

19 Replace the switch-actuating screw.

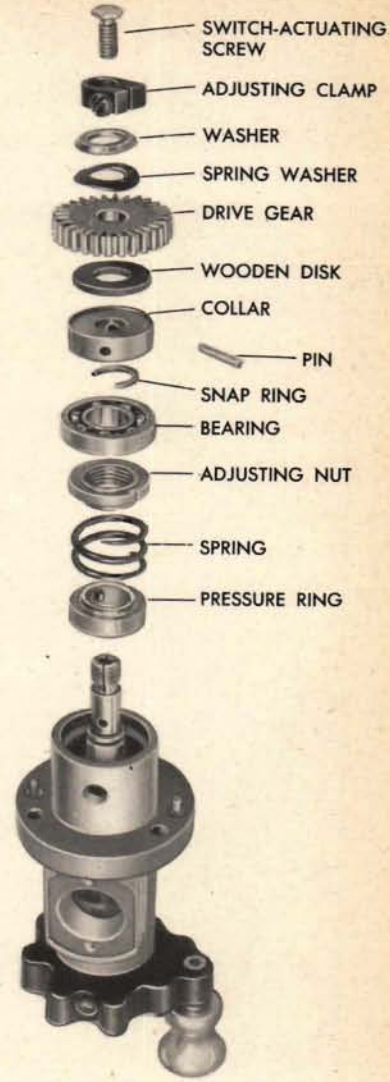
20 Put the washer on the shaft of the shift lever. Mount the shaft in the housing holding the oil-seal ring.

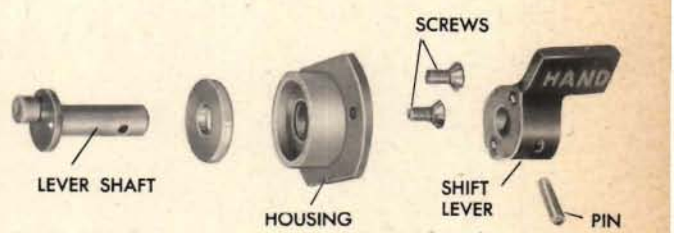
21 Be sure that the small balls can be pressed back flush into the lever and that they spring back to protrude slightly when the force is removed. Pin the lever to the lever shaft.

22 Mount the shift-lever assembly on the adapter, meshing the roller with the sliding collar.

23 Adjust the holding and drive frictions according to the instrument OP.

24 Set the switch-actuating screw so that the push-button switch below the handcrank will operate properly.





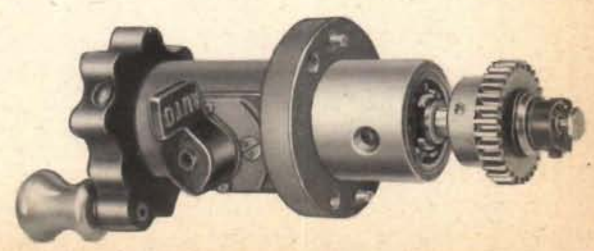
Bench checking the unit

1 Check the assembly of the unit against the assembly drawing.

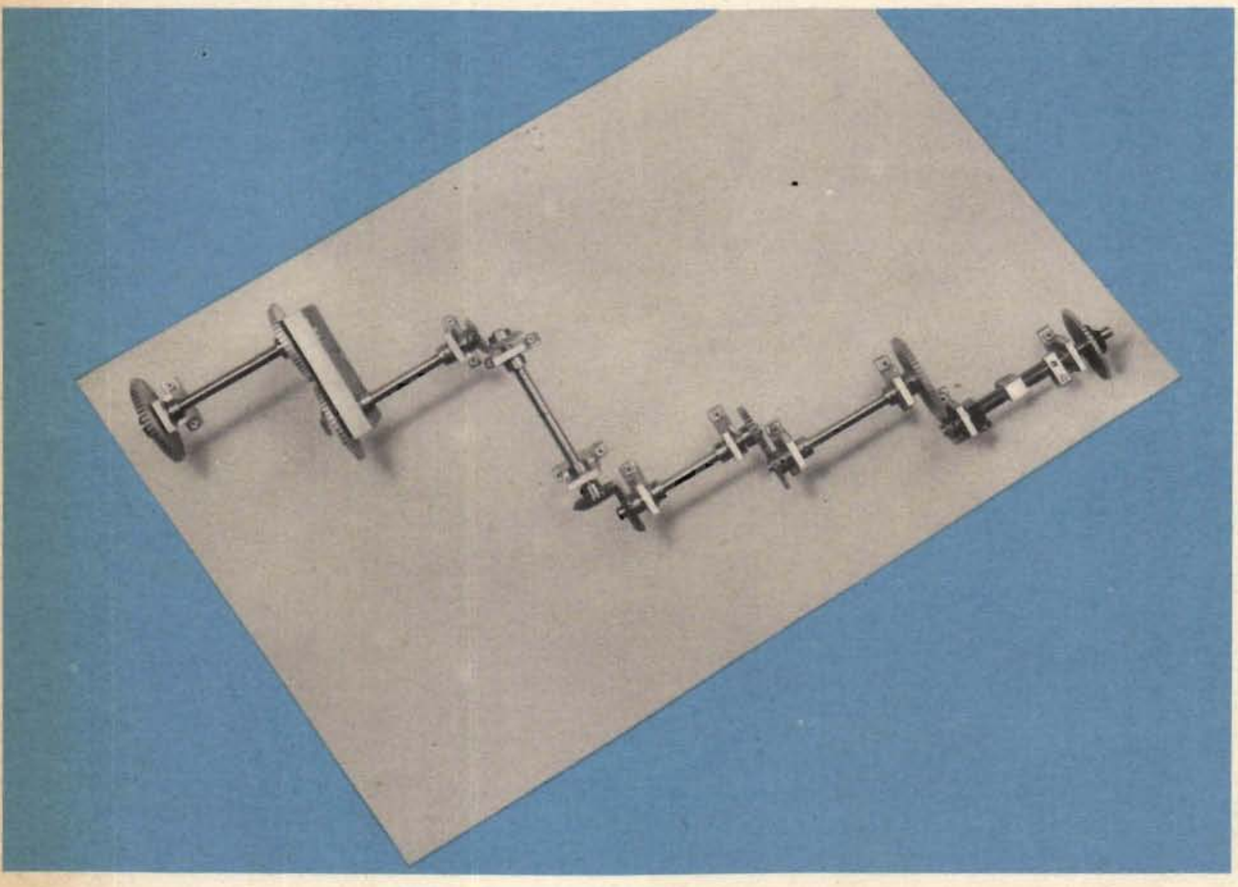
2 The friction should operate smoothly.

3 The handcrank should shift freely and operate smoothly in either position.

4 All moving parts should be lubricated.



SHAFT LINES



A typical shaft line

A shaft line, or gear train, is a series of connected shaft assemblies which carry a value from one point to another. An entire shaft line is rarely mounted on only one plate in an instrument. Usually it is put together in such a way as to turn corners, to go through plates and around units, and so on. For this reason, an entire shaft line can seldom be seen from any one position.

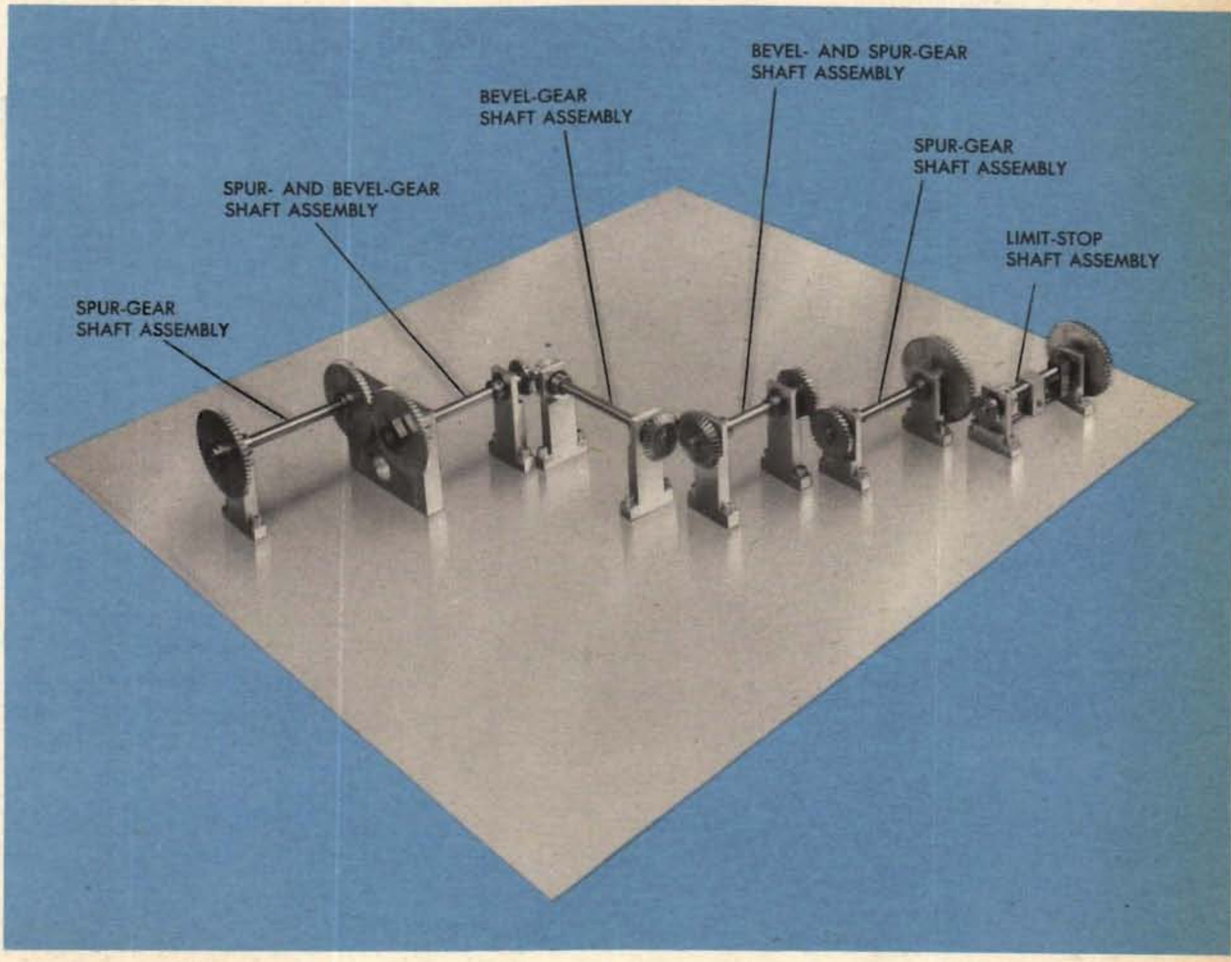
The shaft line shown here was prepared for the purposes of illustration. It does not exist in exactly this form in any instrument, yet it is composed of many of the elements found in actual shaft lines in use. And since it illustrates the principles of shaft lines, it may be considered typical. Study it closely.

This particular line consists of six shaft assemblies, each having two gears:

- a spur-gear shaft assembly
- a spur and bevel-gear shaft assembly
- a bevel-gear shaft assembly
- a bevel and spur-gear shaft assembly
- a spur-gear shaft assembly
- a limit-stop shaft assembly

Except for the small vertical plate which supports the meshing pair of large spur gears, screw-fastened hangers are used to mount all the assemblies on the plate. The vertical plate is fastened from the under side of the mounting plate by screws.

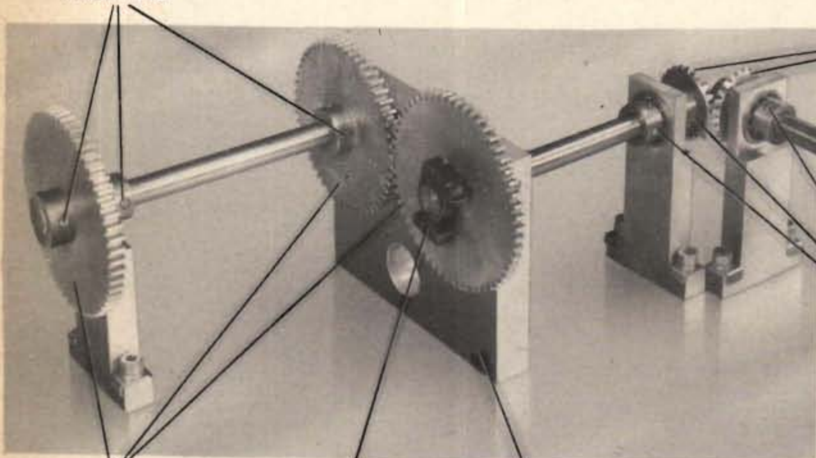
Close-up views of the assemblies which make up this shaft line are presented on the following pages.



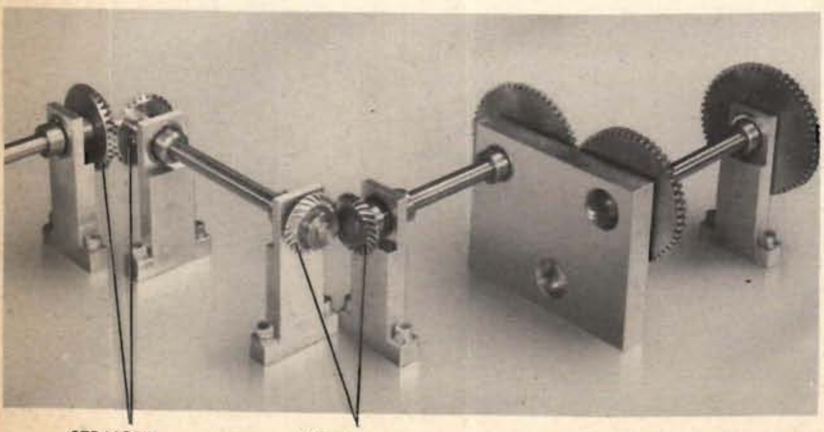
The shaft assemblies in the line

Here are close-up views of the shaft assemblies and meshing gears which make up the shaft line under consideration.

The first two assemblies are connected by meshing spur gears. Each assembly is mounted on a hanger at one end, and they share a vertical plate which functions as a hanger for both. Notice that a clamp fastens one of the meshing spur gears to its shaft. All other parts of both assemblies are taper-pinned. The second assembly is connected to the third by meshing *spiral* bevel gears.

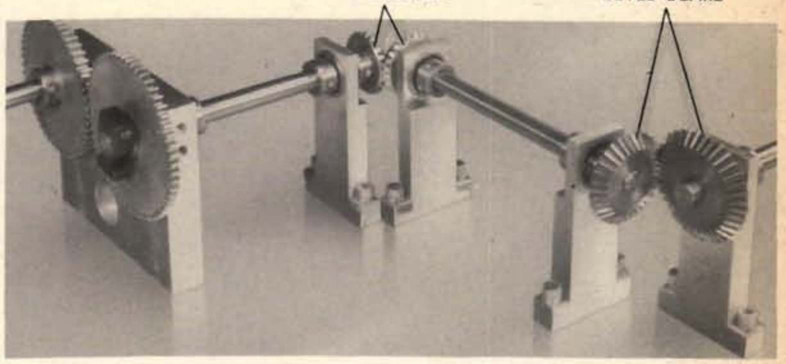


This reverse view shows the spiral bevel mesh and the opposite side of the vertical plate. The third assembly is connected to the fourth by meshing *straight* bevel gears.

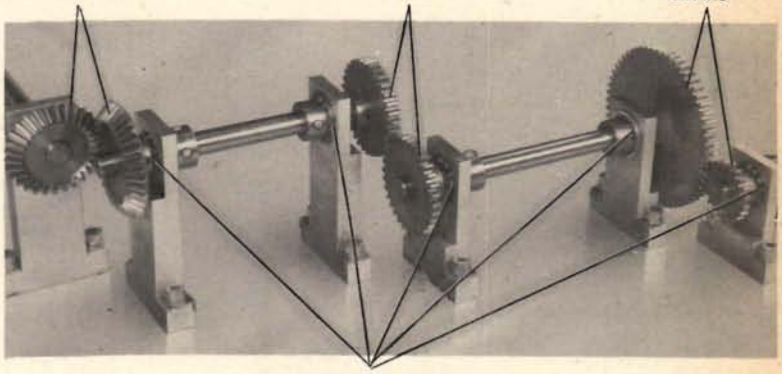


REVERSE VIEW

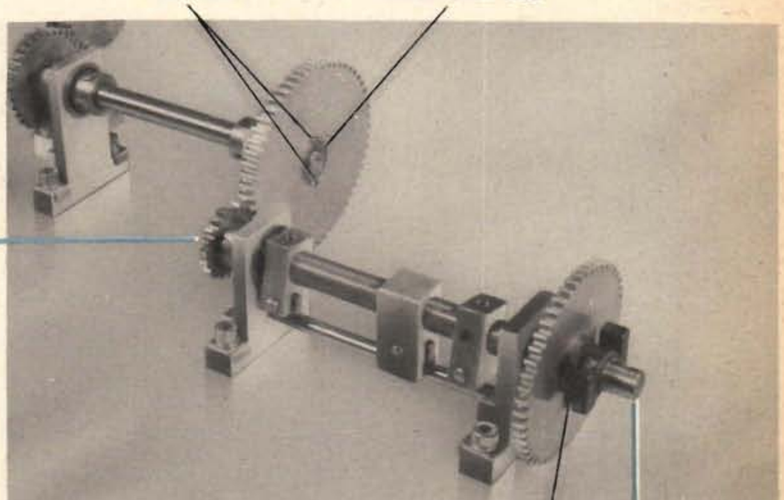
The assembly with a spiral and a straight bevel gear is shown here. Notice the straight bevel gear mesh and the positions of the hangers.

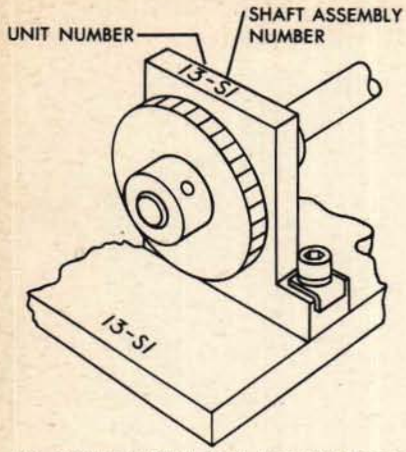


Here are shown details of the fourth and fifth assemblies and three pairs of meshing gears. Notice the ball bearings and the positions of the hangers.



All the parts of the limit stop assembly can be seen here, as well as the large meshing spur gear. Notice the dowels in the large spur gear which insure that the peened-over hub and the gear turn together. The large spur gear on the limit stop assembly is held by a clamp.

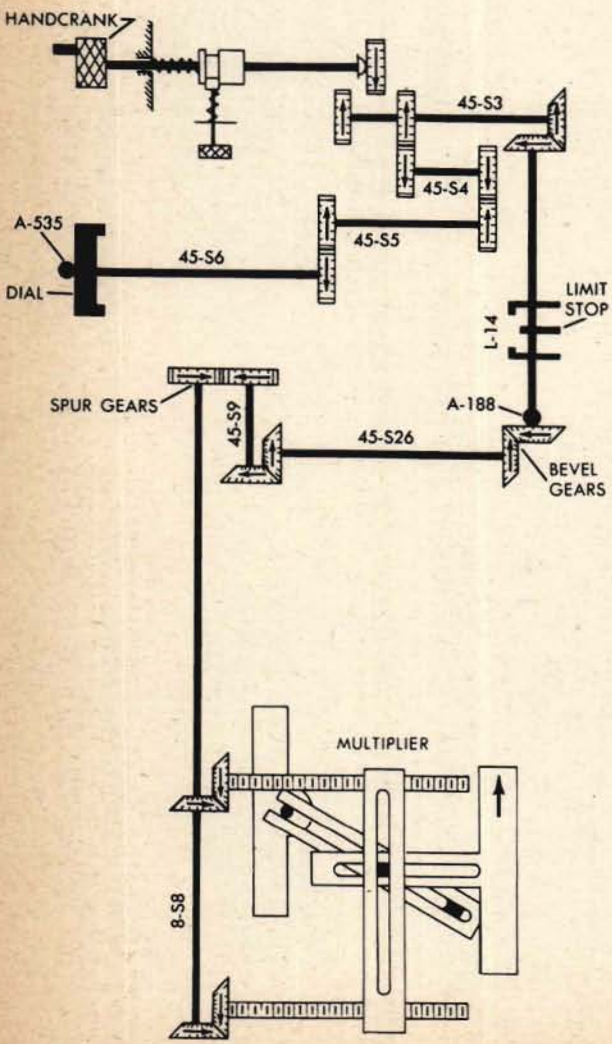




ALL SHAFT ASSEMBLIES ARE NUMBERED

Gearing diagrams

To trace any shaft line through an instrument, it is necessary to follow the instrument gearing diagram. Each shaft assembly on this diagram bears a number which is also stamped on both the corresponding assembly and its mounting surface in the instrument. The first part of this number identifies the unit where the assembly is mounted; the second part identifies the assembly itself.



Here is a small section of a gearing diagram showing one particular shaft line. It necessarily shows all the assemblies as though they were in the same plane, but remember that *in the instrument they are not all mounted on the same plate.* This shaft line carries a quantity from a handcrank to both a dial and a multiplier.

The handcrank is the lock-in, pull-out type. When it is pulled out and turned, a quantity is carried through spur-gear assemblies to a dial, and through a combination of bevel-gear and spur-gear assemblies and a limit stop to a screw type multiplier.

The quantity cranked in is one of the inputs to the multiplier. The other input and the output gears and shafts have been omitted here for the sake of simplicity.

Isolating a faulty shaft line

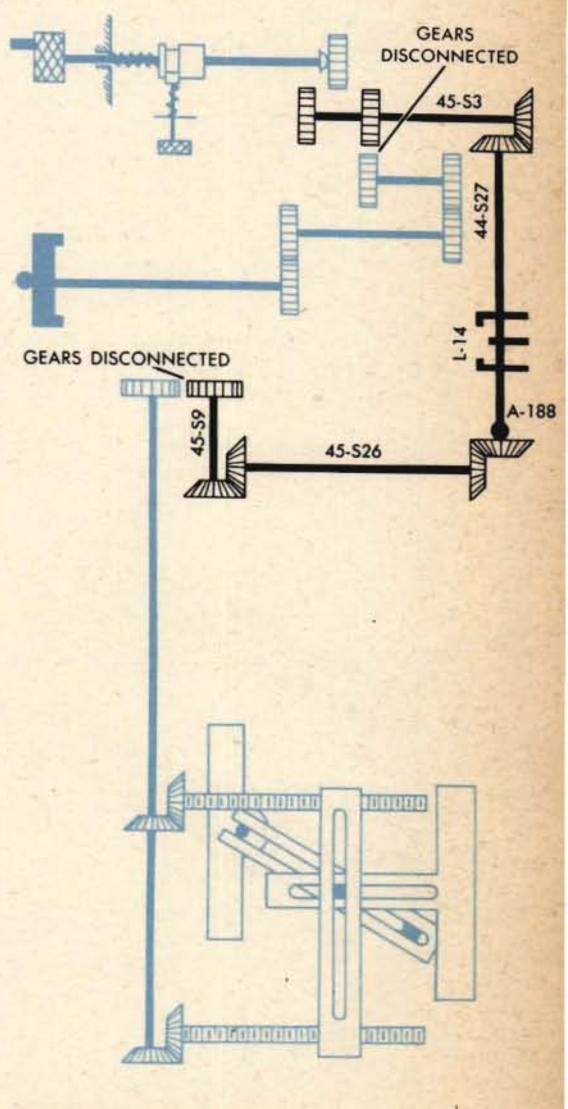
In general, this chapter presents methods of trouble shooting shaft lines as distinct from shaft assemblies. The problem confronted here is that of tracking down the cause of the trouble in a shaft line taken as a whole.

It is assumed that the trouble shooter is already familiar with Part 1 of this OP: *Basic Tools and Operations.* A detailed discussion of repair and maintenance of shaft assemblies as single units is presented in Chapter 2, *Basic Repair Operations.*

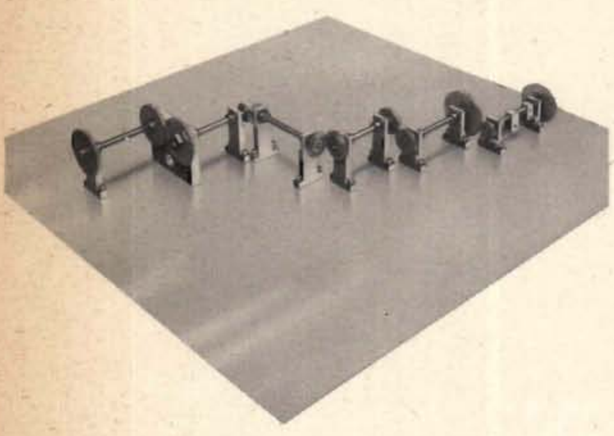
Before trouble shooting any shaft line, be certain that the source of the trouble is in the line itself and not in a connected mechanism. This chapter assumes that the trouble is known to be in a particular shaft line and that the line is disconnected from all units.

A test analysis and unit check tests as described in the instrument OP will help to locate a faulty shaft line. Always remember, however, that a shaft line may *appear* to operate abnormally because a unit to which it is connected is not operating normally.

On the instrument gearing diagram, identify the assemblies which make up the faulty shaft line. It may also be necessary to refer to the assembly drawing after the particular shaft assembly which is the source of the trouble has been found.



IDENTIFYING THE ASSEMBLIES OF AN ISOLATED FAULTY LINE



Typical symptoms

If a shaft line is operating properly, the entire line can be made to turn normally from one end. If this cannot be done, check the line for the following typical symptoms.

JAMMING: The line cannot be turned at all by hand, or requires excessive hand pressure.

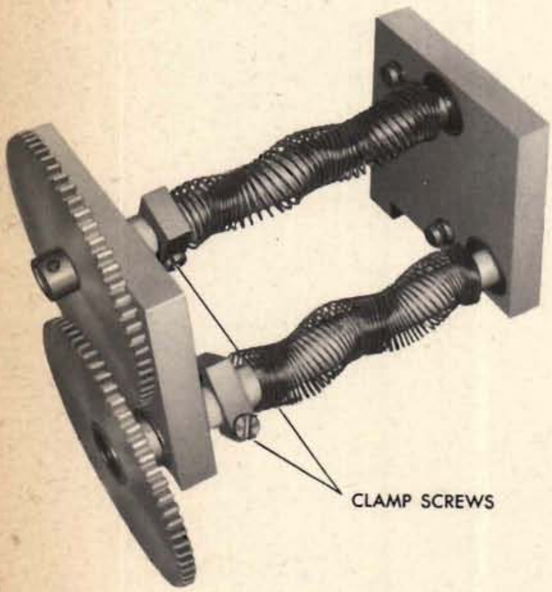
STICKING: The line turns, but a tight spot or a bind can be felt.

EXCESSIVE LOST MOTION: The line turns, but there is too great a lag between the turning of the first assembly and the last.

SLIPPING: If the last assembly in the line is held stationary, turning the first assembly does not turn all the others.

Locating the cause

LOST-MOTION TAKE-UP SPRINGS



To restore normal operation in a shaft line, it is necessary first to locate the cause of the trouble in a particular shaft assembly, or pair of meshing gears, and then to make whatever repair is needed.

There are two general methods of tracking down the source of trouble in a shaft line:

Checking the *accumulated lost motion* and the *increments* of accumulated lost motion in the line.

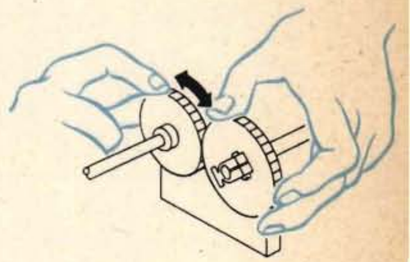
Checking the lost motion *at each gear mesh throughout the line.*

Either of these methods or a combination of both may be used, depending on the nature of the shaft line and the shaft assemblies of which it is made up.

If there is a lost-motion take-up spring anywhere in the line, the clamp should be loosened to free the spring before the line is checked for lost motion. If the spring clamp is not loosened, an accurate check of the line cannot be made.

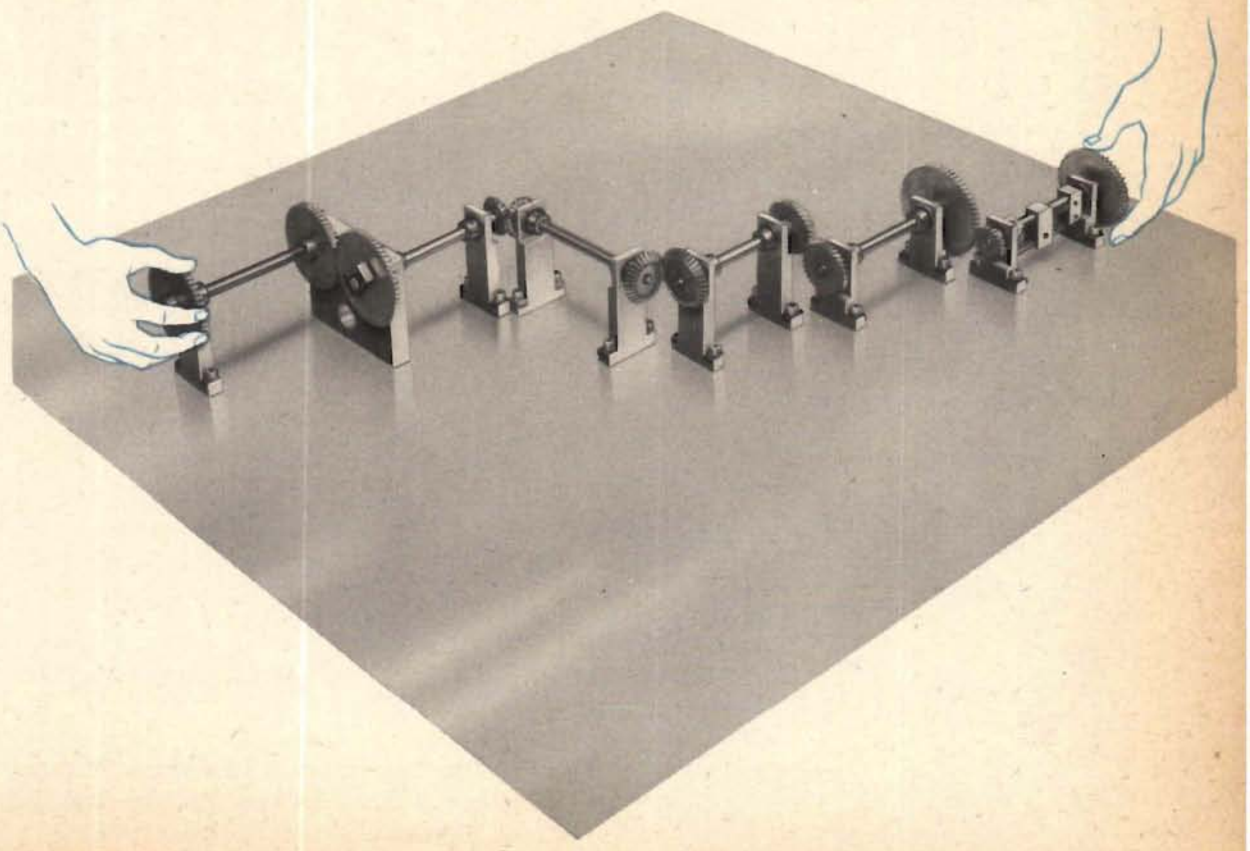
Checking accumulated lost motion

Accumulated lost motion is the total of all the lost motion throughout a shaft line. It can be felt by holding the gear *at one end* of the shaft line stationary and turning the gear at the *opposite end* of the line slowly back and forth. The amount of lost motion felt in this way is the accumulated lost motion in the entire line. Increments of accumulated lost motion can be felt by holding a gear stationary at one end of the line and turning each gear in succession from the opposite end.



This general procedure can be used to locate the source of jamming, sticking, excessive lost motion, or slipping in a shaft line. In a slipping line, it is necessary to hold one gear and try to turn each of the others through a complete revolution.

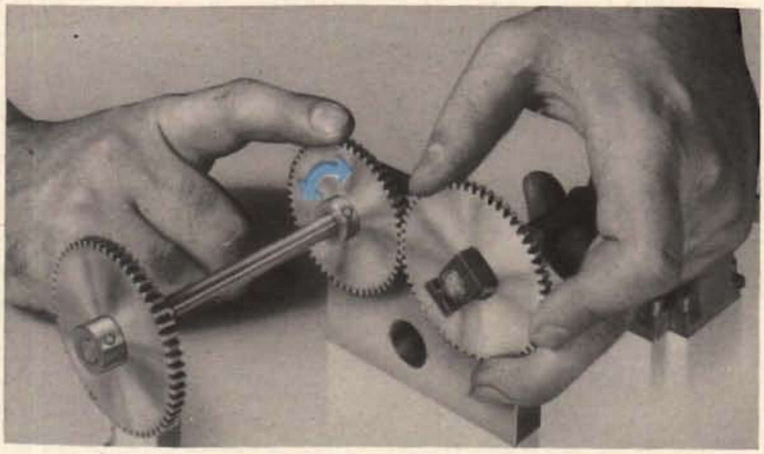
CHECKING ACCUMULATED LOST MOTION IN AN ENTIRE SHAFT LINE

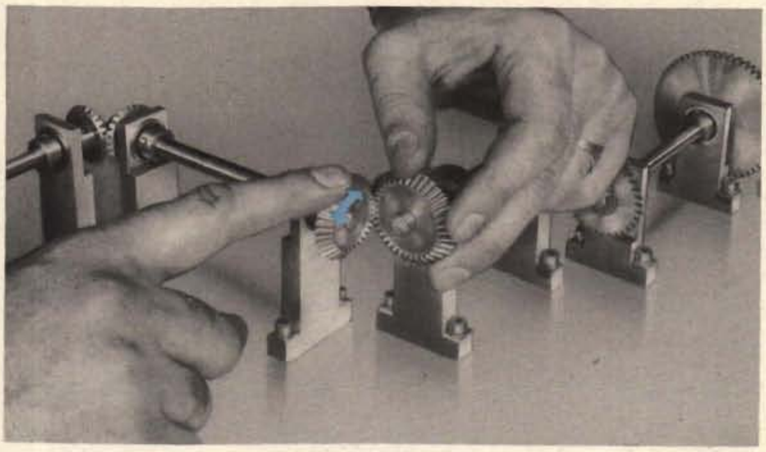


Checking lost motion at each gear mesh

It is often possible to track down the cause of the trouble to one or two shaft assemblies by starting at the first gear mesh at either end of a shaft line and checking for lost motion at each mesh in succession throughout the line. This method is especially useful where a line normally carries a heavy load and is therefore difficult to turn by hand.

Remember that lost motion at a gear mesh is measured as the distance the driver gear turns before the driven gear is turned. It can be accurately measured with a dial indicator, but for trouble shooting a shaft line it can be felt by hand. This is done by holding one of the two meshing gears stationary and turning the other slowly back and forth.





Beginning at either end of the line, check each pair of meshing gears in this way until some symptom of abnormal operation is found: jamming, sticking, excessive lost motion, or slipping.

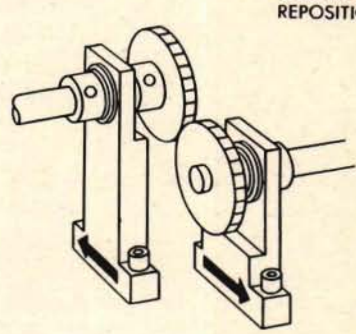
Jamming

A shaft line may jam because of dirty or damaged gears or bearings, or because of a bent shaft in one or more of the shaft assemblies which make up the line. *Never force a jammed line to turn.* Forcing a line may bend a shaft, damage a gear, or otherwise put too much strain on some assembly in the line. Use one or both lost motion checks to locate the source of the trouble in a particular shaft assembly or gear mesh.

In a jammed line, the farther a gear mesh is from the point of jamming, the more accumulated lost motion can be felt in it. As the checking proceeds from mesh to mesh toward the point of jamming, less and less lost motion can be felt until the jammed gears are reached.

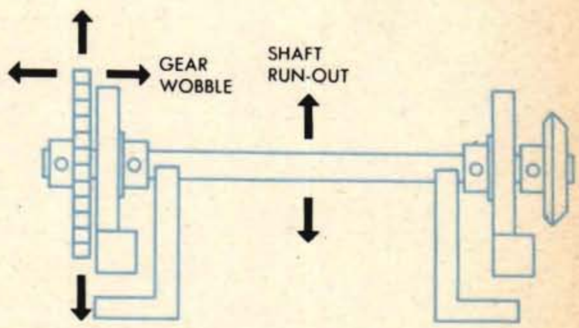
If a jammed spur-gear assembly is mounted on hangers or an adapter, loosen the screws. If the gears then turn freely, position the hanger or adapter for correct lost motion and tighten the screws. Unless the shaft is bent or the bearings are dirty or damaged, this repositioning will eliminate jamming caused by a tight spur-gear mesh.

JAMMED SPUR GEARS : SCREWS LOOSENED TO REPOSITION HANGERS



For an explanation of the proper method of positioning bevel-gear assemblies, study pages 54–55.

A bent shaft or defective bearings will continue to jam the shaft line. To repair either of them, the shaft assembly should be removed from the instrument. Study its location and connections to see how it can best be removed.



With the assembly on the bench, inspect the gear teeth and bearings for foreign matter and damage, and check shaft and gear run-out. Repair or replace the part which is causing the assembly to jam. *Be sure to stake all taper pins during reassembly and to remove all set screws.*

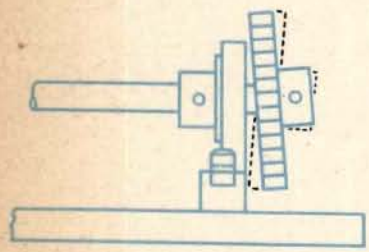
Before reinstalling the assembly, check the other assemblies in the line for smoothness of operation. Finally, reinstall the assembly and check it in place for correct end play and lost motion.

Sticking

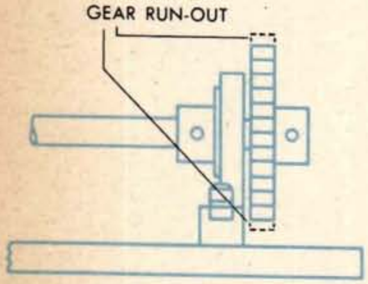
A shaft line may stick because of loose hangers, a bent shaft, or defective gear teeth or bearings in one or more assemblies in the line.

Check the hangers first and tighten any that are loose.

GEAR SIDE-WOBBLE



GEAR RUN-OUT



To determine whether a shaft is bent, turn the gears by hand until a tight spot or a bind is felt. Then check the gear meshes for lost motion, just as in a jammed line, to narrow down the cause of the trouble to one or two assemblies.

Check the shaft by eye for run-out; turn it by hand and watch closely to see if the gears wobble or the shaft hops. If either of these faults is found, the shaft assembly should be removed from the instrument for repair.

Dirty or damaged gear teeth may cause a gear to stick once during each complete rotation. First check the gears on the assemblies which stick or bind once for each turn. Inspect them for nicks and dents, chips, or embedded particles. If the gear teeth are badly damaged, the shaft assembly should be removed from the instrument for repair.

If the shafts are all straight and lost motion is uniform throughout the line, defective bearings may be causing an assembly to stick. If the bearings are dirty, remove the shaft assembly in which they are mounted and wash them thoroughly in a suitable solvent. Never attempt to wash bearings inside the instrument unless removal is extremely difficult.

After the bearings have been cleaned or replaced, check the shaft assembly for shaft and gear run-out. If necessary straighten the shaft and replace worn or defective parts. Before installing a repaired shaft assembly, check the remaining assemblies in the line for run-out and smoothness of operation.

Finally, reinstall the assembly and check it in place for end play and lost motion.

Excessive lost motion

Excessive lost motion in a shaft line may be caused by worn gears at a single gear mesh, loose or shifted hangers, or slightly worn gears throughout the line.

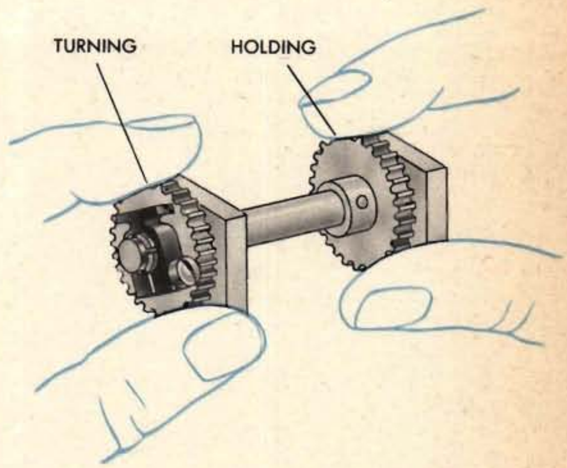
Sometimes excessive lost motion is caused by slightly worn gears throughout the line rather than by worn gears at one or two meshes. It is not always possible to reach all the shaft assemblies to reposition them. By sufficiently reducing lost motion at those assemblies which can be reached, however, it may be possible to reduce the total accumulated lost motion in the line so that it will operate normally.

Slipping

Slipping, or failure of all the assemblies in a shaft line to turn together, may be caused by loose hangers, stripped gear teeth, loose clamps, or missing or sheared taper pins or dowels.

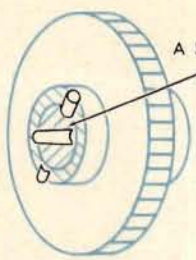
To locate a particular assembly which is slipping, follow a procedure similar to that used to check accumulated lost motion and increments of accumulated lost motion. Hold the gear at one end of the line and, beginning at the opposite end, try to turn each of the other gears through a complete revolution.

Examine the hangers to see whether there are any loose or missing screws. Missing screws may allow a hanger to shift far enough to move a gear out of mesh. Reposition the hangers if necessary.



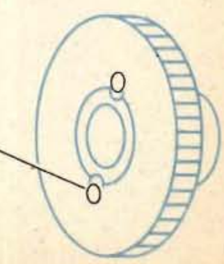
Examine the gears for stripped teeth. If any are found, replace the gears.

Test for a loose clamp by holding the shaft and trying to turn the gear. Clamp slots sometimes close entirely without holding the hub firmly against the shaft. Such clamps must be replaced.



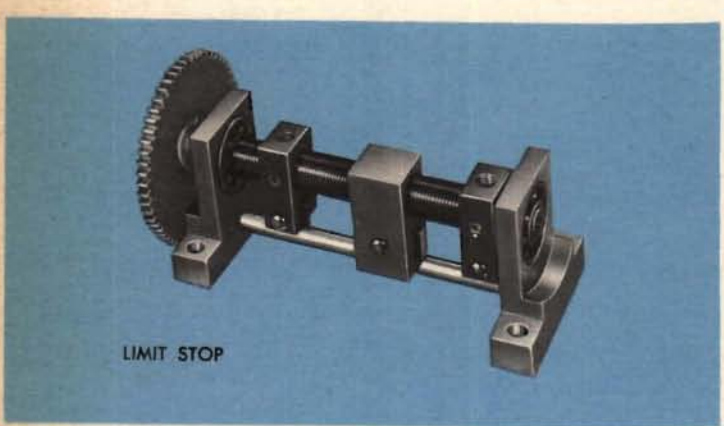
Inspect all hubs for missing taper pins. Test for sheared taper pins or dowels by holding each gear and turning its shaft until the slipping gear is found.

To redowel or repin a slipping gear, first remove it from the shaft. Tap the pieces of a sheared taper pin from the gear and shaft separately. Examine the parts carefully and replace any that are damaged.



Inspect a gear with missing dowels to see whether the hub or gear has been damaged. If the fit is a little too loose, it can be tightened by peening. Check the gear for run-out before redoweling it. For doweling and riveting procedures, see pages 74-79

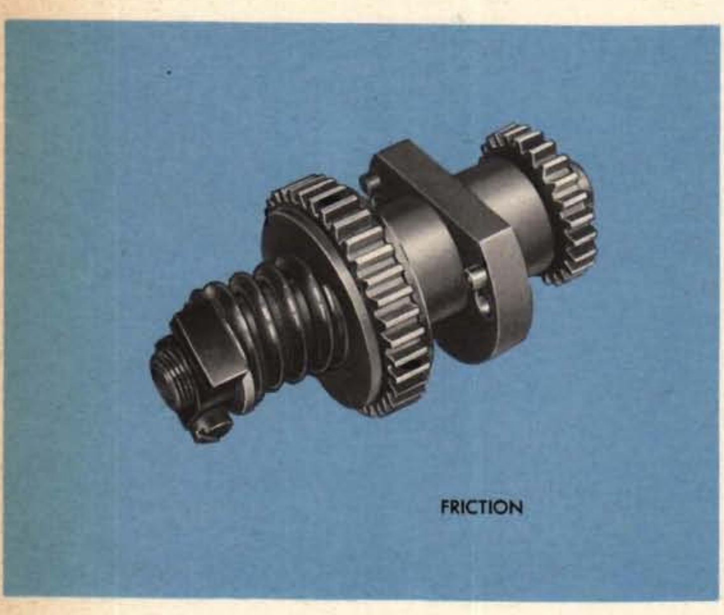
SHAFT LINE DEVICES



LIMIT STOP

This chapter deals with six common devices which are used for special purposes in shaft lines. They perform such functions as limiting the number of turns made by a shaft line, guiding a shaft line into a definite position and holding it there, joining two shaft ends, protecting mechanisms, eliminating excessive lost motion, and making fine adjustments possible.

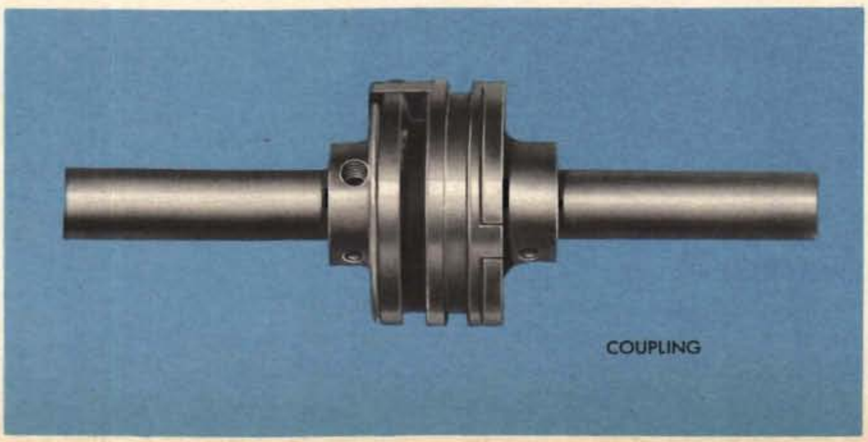
A LIMIT STOP protects delicate mechanisms by limiting the number of turns of the shaft line to which it is connected.



FRICTION

A FRICTION eases the strain on delicate mechanisms by slipping when the driving force becomes too great. Some types of frictions hold shaft lines so as to prevent values from backing out.

A COUPLING joins two shafts together so that they function as one. It can also serve as an expansion joint, compensate for misalignment of shafts, hold a removable shaft in place, or connect one unit directly to another.

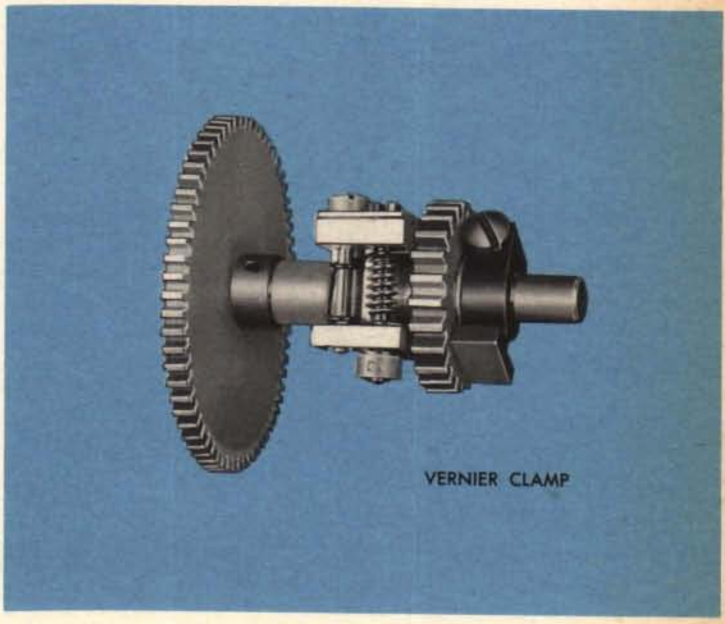


COUPLING

A DETENT guides a shaft into a definite position and holds it there until another position is required. It is used where a limited number of values must be set quickly and accurately.

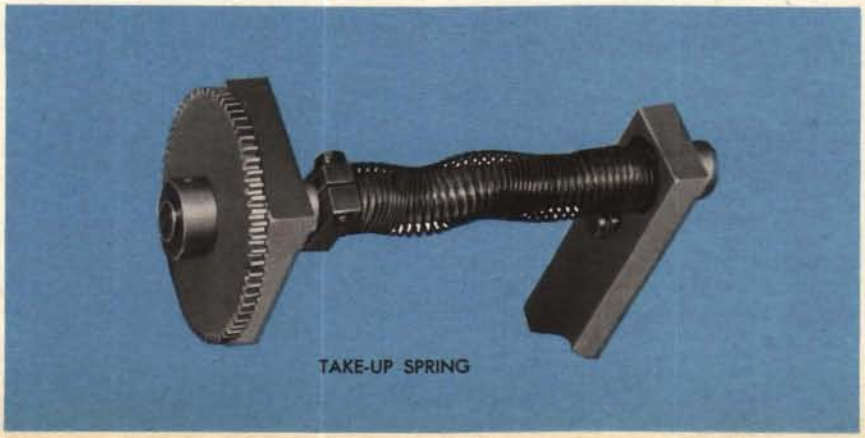
DETENT

A VERNIER CLAMP is used to make fine adjustments in the position of one gear in relation to another.



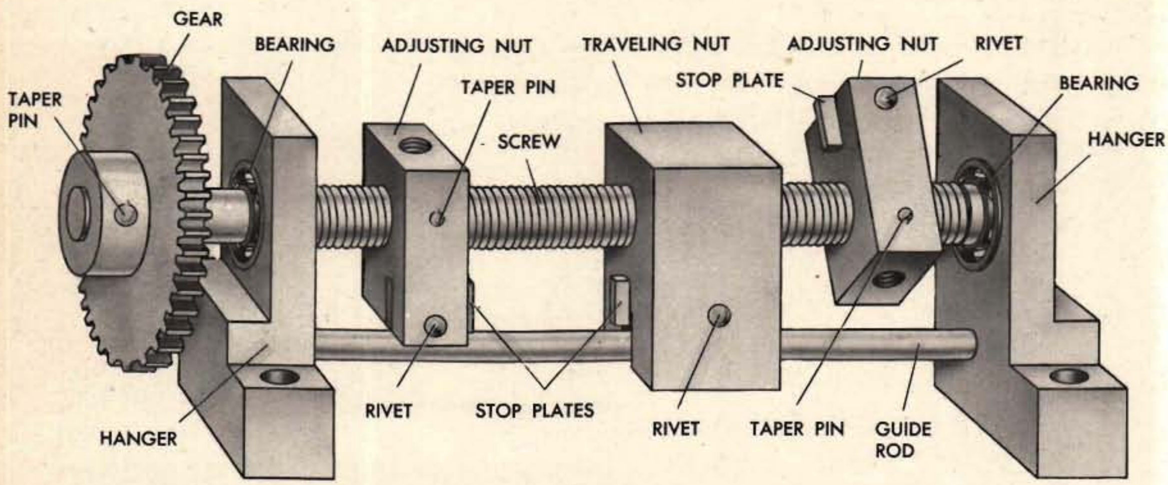
VERNIER CLAMP

A TAKE-UP SPRING eliminates lost motion between meshing gears by supplying enough tension to a shaft line to hold a driving gear firmly against a driven gear.



TAKE-UP SPRING

THE LIMIT STOP



A limit stop is a safety device in a shaft line between two mechanisms. Its job is to prevent a shaft from turning too far and possibly damaging the connected mechanisms. Since a limit stop is essentially a shaft assembly, many of the repair operations are the same as for shaft assemblies.

In order to remove the limit stop for repair, remove the screws holding each of the two hangers to the plate and carefully lift out the unit. Before removing the unit, consult the instrument OP for instructions.

Typical symptoms

If a test analysis and shaft line check indicate that a limit stop is not operating normally, look for one or more of the following typical symptoms:

JAMMING: The limit stop cannot be turned by hand.

STICKING: When the limit stop is rotated, the screw turns sluggishly or resists turning past certain points.

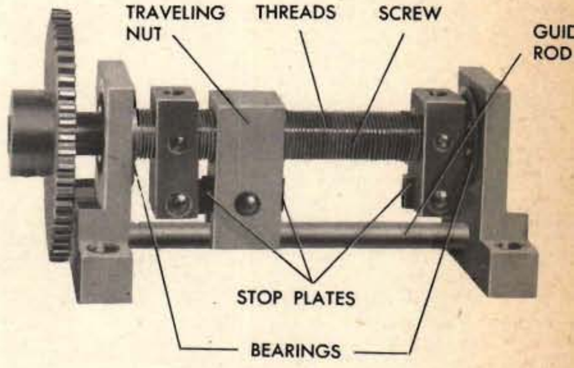
SLIPPING: The gear can be turned after the traveling-nut stop plate reaches one of the adjusting-nut stop plates, or the screw turns intermittently or not at all when the gear is rotated.

EXCESSIVE LOST MOTION: There is too much play between the threads of the traveling nut and the screw.

Locating the cause

Jamming or sticking

A limit stop may jam or stick because of dirty or damaged bearings or threads, a bent guide rod or screw, or a loose stop plate. Bearings or threads may sometimes be cleaned with an approved solvent without disassembly. If the limit stop then operates satisfactorily, apply a lubricant to the screw and turn the traveling nut back and forth through its full travel. If cleaning does not eliminate jamming or sticking, proper running-in with the unit removed from the instrument is sometimes effective.



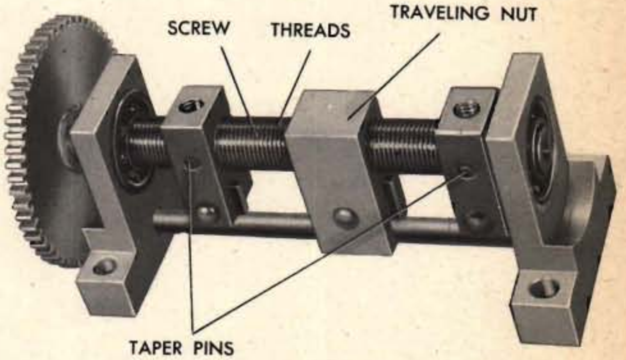
CAUTION: Too much running-in will wear the threads. The compound must be kept out of the bearings. Damaged bearings or threads usually require disassembly of the unit and replacement of the damaged parts.

A bent screw should be replaced. If the guide rod is not badly bent, it may be straightened without disassembly. A badly bent guide rod requires disassembly of the unit for repair or replacement.

A loose stop plate may stop the traveling nut before it reaches one of its limits or may cause improper clearance between the stop plates. A loose stop plate requires disassembly of the unit for repair.

Slipping

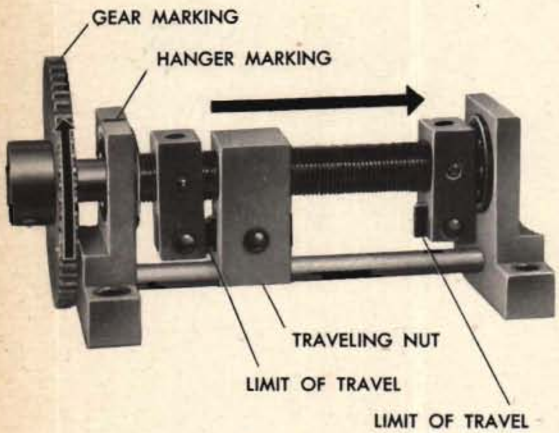
Slipping may result if a taper pin is sheared or missing. The unit should be disassembled and the taper pin replaced.



Excessive lost motion

Excessive lost motion between the traveling nut and the screw is caused by worn threads. This condition may cause the traveling nut to jump one revolution so that it does not make the specified number of turns. The unit should be disassembled and the worn parts replaced.

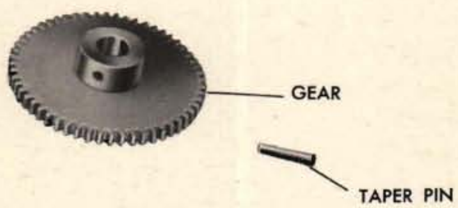
Disassembling the unit

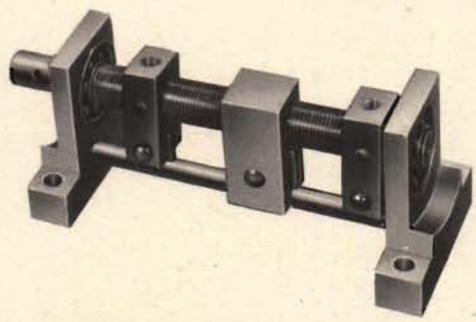


Before disassembling the limit stop, count the number of turns of the gear required to move the traveling nut from one limit to the other. One method of counting the turns is to turn the stop until the traveling nut is at either limit. Indicate the position of the gear by marking both the gear and its hanger. These marks make it possible to determine the exact number of turns made by the gear in order to move the traveling nut to the other limit. For example, if a 20-tooth gear turns 3 full turns plus 10 teeth, the screw has turned 3.50 turns. The number of turns should be not less than the number specified on the assembly drawing and not over 0.02 of one turn more.

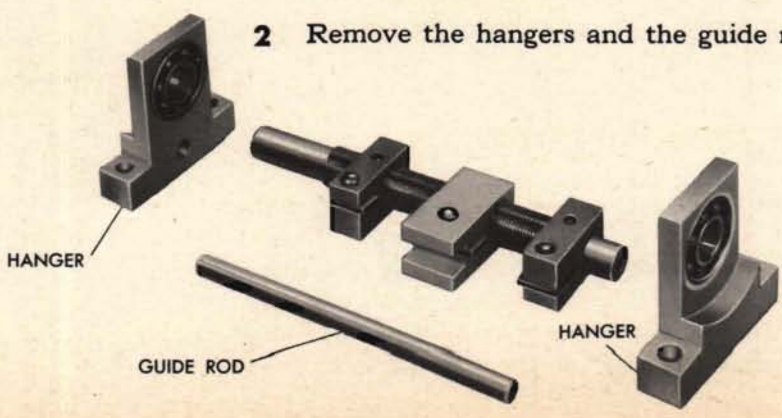
During disassembly be sure to tag the hangers, adjusting nuts, and traveling nut in order to indicate their position in relation to the gear end of the limit stop. It is important not to reverse these parts when the unit is reassembled.

1 Drive out the taper pin in the gear hub and remove the gear.



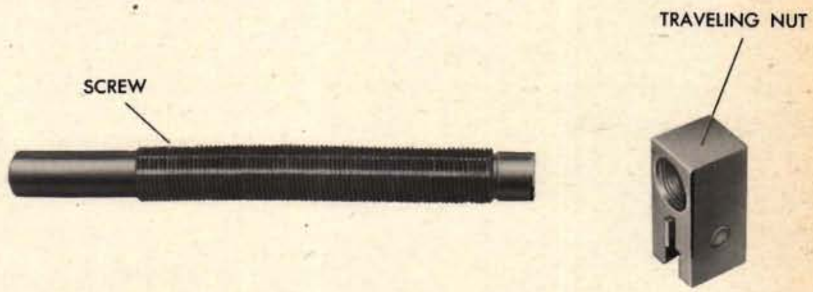


2 Remove the hangers and the guide rod.



3 Drive the taper pins out of the adjusting nuts, and unscrew the nuts. Be careful not to damage the screw.

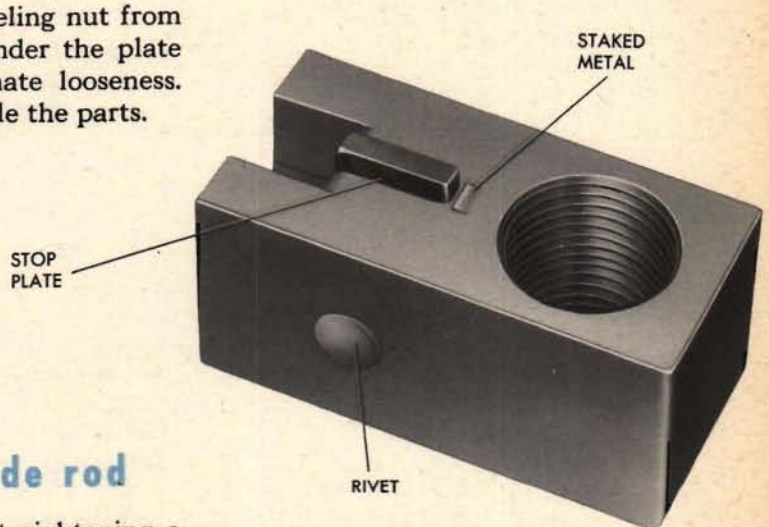
4 Turn the screw out of the traveling nut.



Repairing the parts

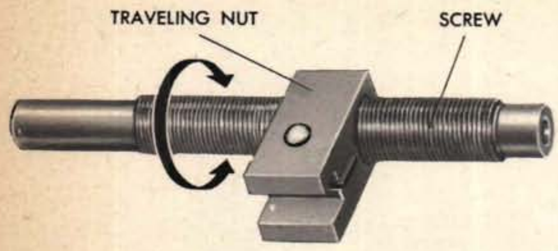
Repairing a loose stop plate

Remove the adjusting or traveling nut from the unit, stake some metal under the plate and reset the rivet to eliminate looseness. Clean, lubricate, and reassemble the parts.



Straightening a guide rod

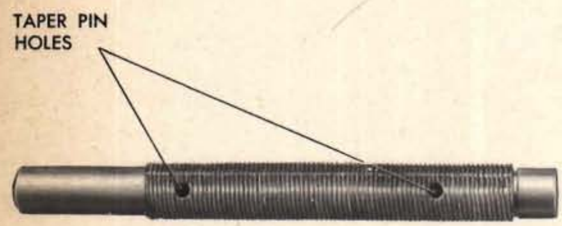
This operation is similar to straightening a shaft. Mount the rod in V-blocks or pinning supports and tap it lightly with a plastic hammer. Use a dial indicator to measure run-out.



Replacing a traveling nut

Clean the screw and the new traveling nut thoroughly with an approved solvent and then lubricate them lightly. Turn the screw into the nut. The screw should turn smoothly in the nut with a minimum of lost motion. If the fit is too tight, run the screw in and out until it does turn smoothly. Clean and lubricate the screw and nut after a running-in operation.

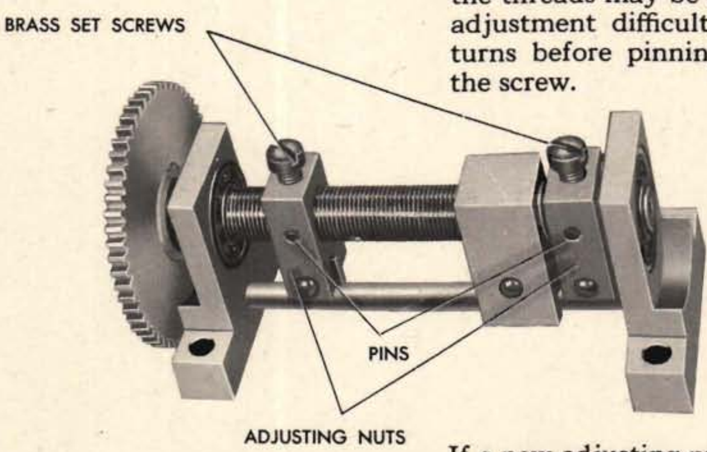
When the stop plates are one turn away from engaging, the clearance between them should be 0.006 to 0.010 inch. If necessary, file the plate or plates to obtain this clearance.



Replacing a screw or an adjusting nut

If it is necessary to install a new limit-stop screw, the adjusting nuts must be correctly positioned and held by brass set screws for pinning. Mount one adjusting nut on the limit-stop screw and tighten the brass set screw. Mount the traveling nut. Mount the other adjusting nut but do not tighten the brass set screw until the nuts are positioned the correct number of turns apart. Pin the adjusting nuts to the screw.

CAUTION: If the set screw in the second adjusting nut is completely tightened too soon, the threads may be damaged and make final adjustment difficult. Check the number of turns before pinning the adjusting nuts to the screw.



If a new adjusting nut is to be installed, difficulty in lining up the old pin holes in the screw with the new pin holes in the nut will be encountered. To avoid this trouble, it is suggested that both adjusting nuts be repositioned on the screw. Move the nut that is to remain to a new location on the screw to assure a complete new hole. Use this position as a base to position the new adjusting nut. While this procedure may be necessary in an emergency, it is better to rebuild the limit stop with a new screw as well as new adjusting nuts.

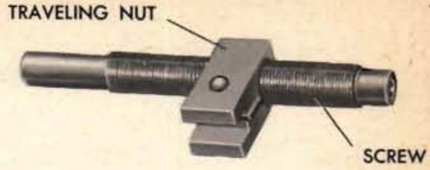
Reassembling the unit

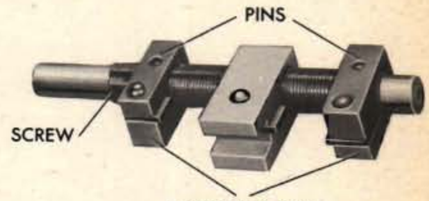
1 Turn the screw into the traveling nut.

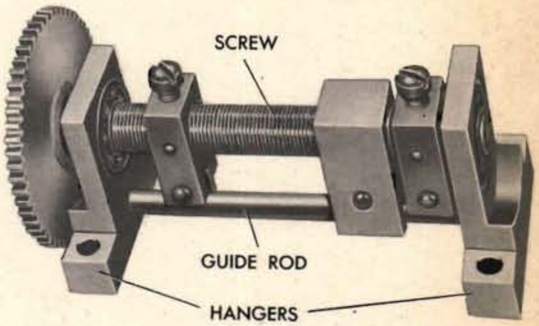
2 Position the adjusting nuts on the screw and pin them.

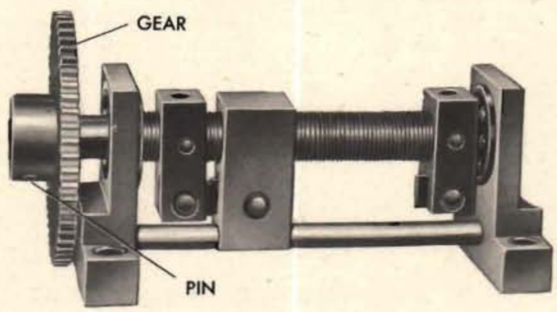
3 Mount the screw and guide rod in the hangers.

4 Pin the gear to the shaft.









Bench checking the unit

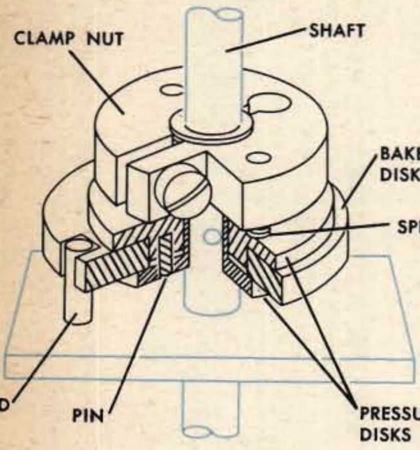
The number of turns of the screw needed to move the traveling nut from the stop plate in one adjusting nut to the stop plate in the other adjusting nut should be the full number specified on the assembly drawing. It should not be over 0.02 of a turn more.

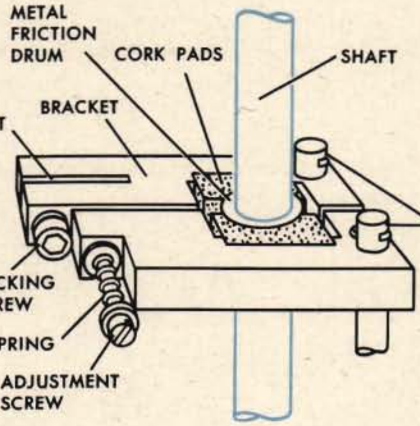
There should be 0.006 to 0.010-inch clearance between the stop plate on the traveling nut and the stop plates on the adjusting nuts when the traveling nut is one revolution from either limit.

The traveling nut should move freely from one limit to the other.

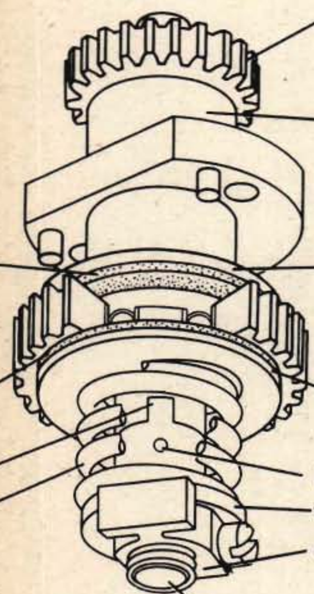
The limit stop should be washed and lubricated.

FRICTIONS





HOLDING FRICTIONS



SAFETY FRICTION

Holding frictions and safety frictions are the most common types.

A holding friction prevents values from backing out through a shaft line.

In one kind of holding friction, the friction is generated by spring pressure squeezing a bakelite disk between two metal disks. The spring pressure is regulated by adjusting a clamp nut on a threaded hub. In another kind, the friction is generated by clamping a metal drum between two cork-lined brackets. In this holding friction, the spring pressure is regulated by turning an adjustment screw.

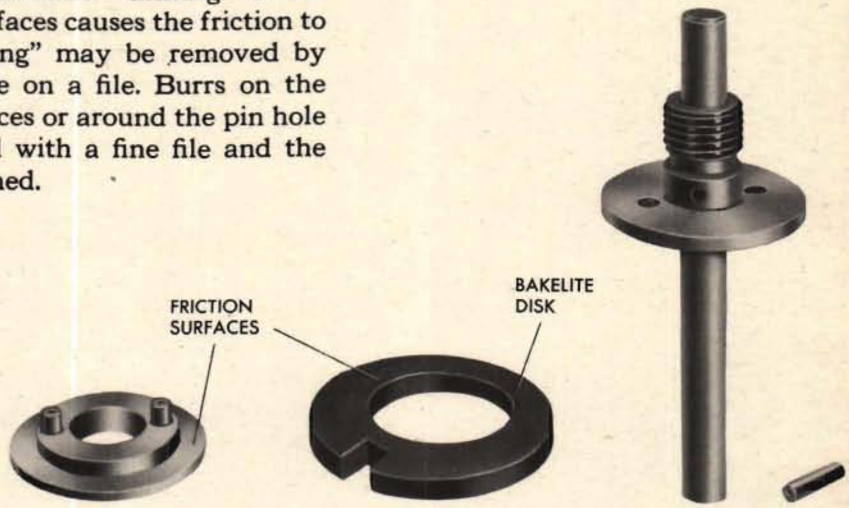
A safety friction prevents damage to mechanisms by limiting the amount of torque transmitted by a shaft line.

For a discussion of handcrank holding and safety frictions, see pages 82-83.

Repairing the parts

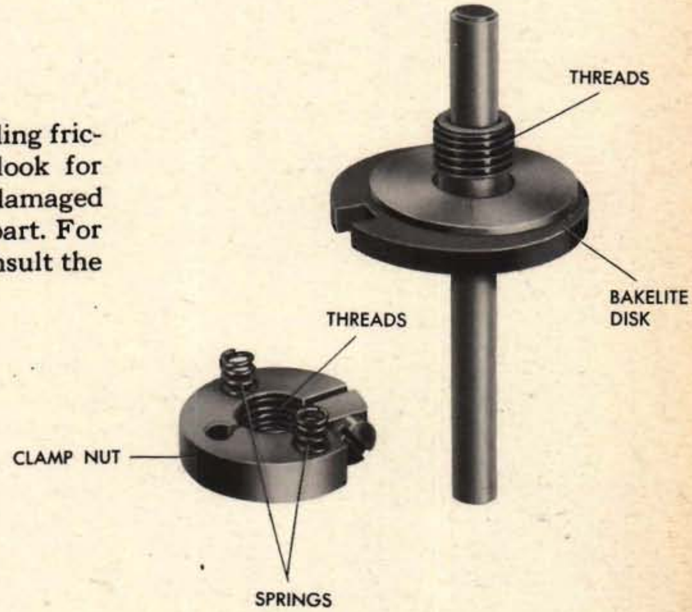
Cleaning friction surfaces

A bakelite disk or cork ring can be cleaned with an approved solvent. "Glazing" of the bakelite or cork surfaces causes the friction to chatter. The "glazing" may be removed by rubbing the surface on a file. Burrs on the metal friction surfaces or around the pin hole should be removed with a fine file and the surfaces then polished.



Adjusting a clamp nut

If the clamp nut on a screw-type holding friction cannot be adjusted properly, look for dirty or damaged threads. Badly damaged threads require replacement of the part. For the proper adjustment procedure, consult the instrument OP.

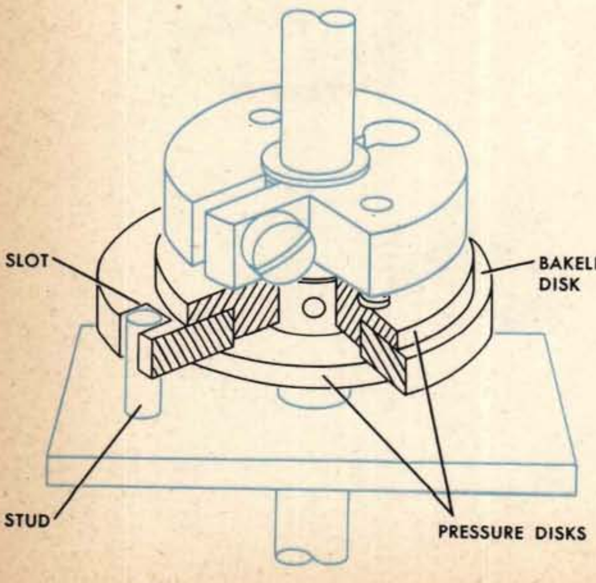


Freeing a friction gear

A safety friction in which the friction gear turns directly on a shaft instead of on a bearing may freeze on the shaft so that it will not slip. Complete disassembly of the unit is required in order to polish the shaft and the hole in the gear. The gear and both disks should be checked for run-out, and straightened if necessary.

Cementing a cork disk

If the cork disk has come loose from the gear, disassembly is necessary in order to cement the parts together again. Use the materials furnished in the lubrication kit. See the suggestions in the *Introduction,* page 18.

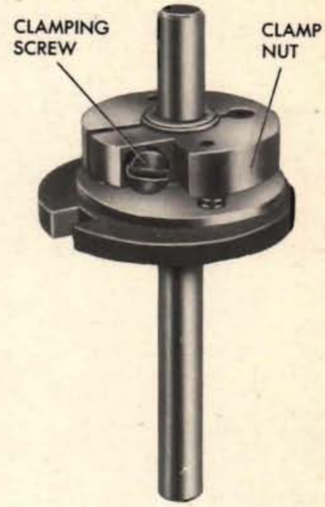


Replacing disks

Refer to the assembly drawing of a screw-type friction for the tolerance between the stud and slot in the bakelite disk. If there is too much play, it is best to replace the damaged part or parts. If the pressure disk which is pinned to a shaft wobbles, it may cause uneven operation of the friction. A wobbling disk should be repaired in the same way a wobbling spur gear is repaired.

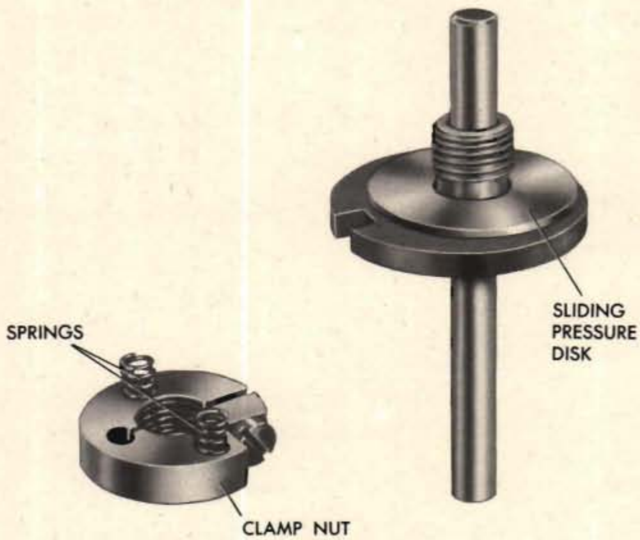
Disassembling the unit

Holding friction

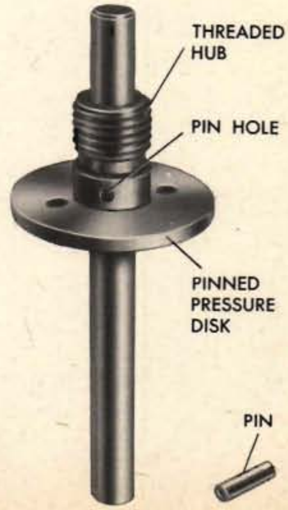


1 Loosen the clamping screw and unscrew the clamp nut from the threaded hub. Do not lose the two coil springs.

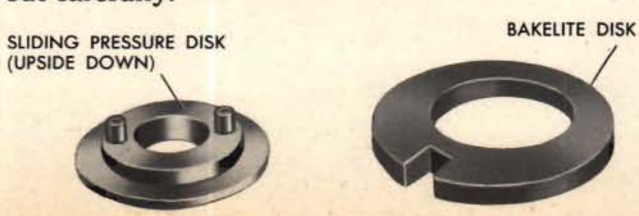
2 Remove the sliding pressure disk.

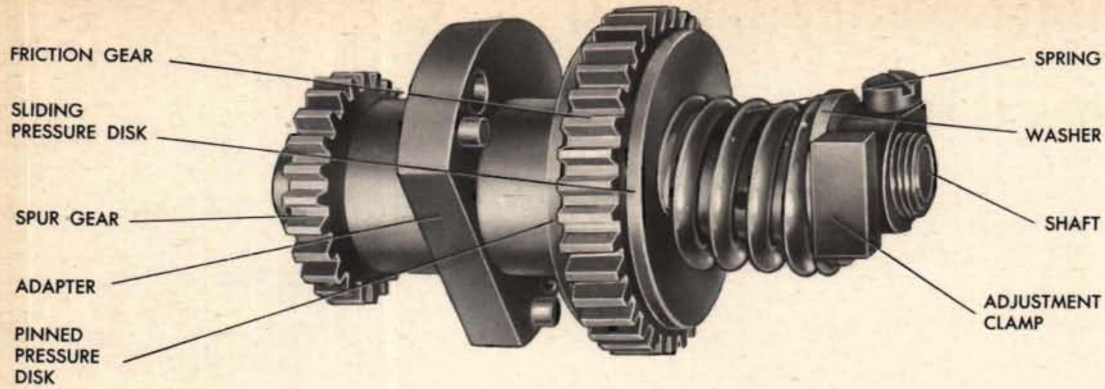


3 Remove the bakelite disk.

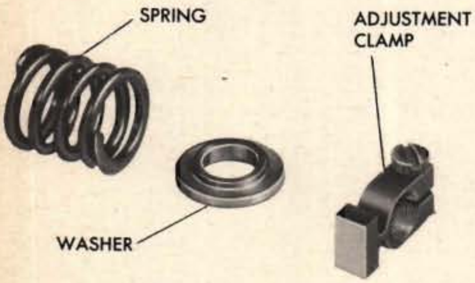


4 Most repairs can be made without removing the threaded hub. If it is necessary to remove the hub and the disk, drive the pin out carefully.





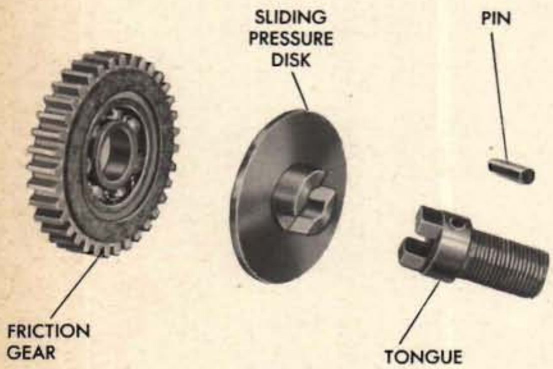
Safety friction



1 Loosen the adjustment clamp and unscrew it from the shaft.

2 Remove the washer.

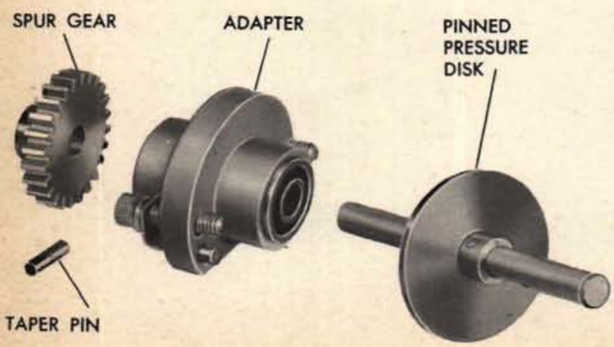
3 Remove the spring from the shaft.



4 Drive the pin out of the tongue and remove the tongue from the shaft.

5 Remove the sliding pressure disk.

6 Remove the friction gear. Do not remove the cork rings from the gear unless they must be replaced.

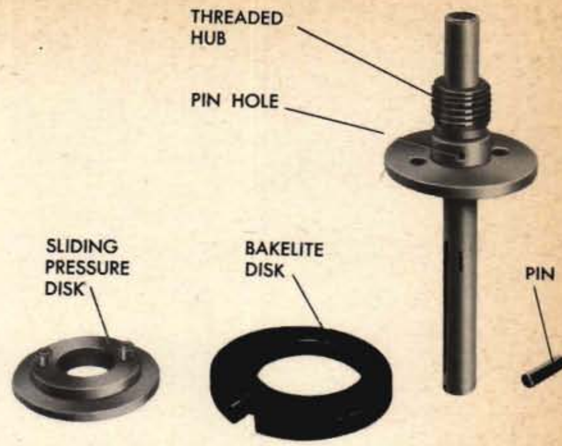


7 Drive the taper pin out of the spur-gear hub and pull off the gear.

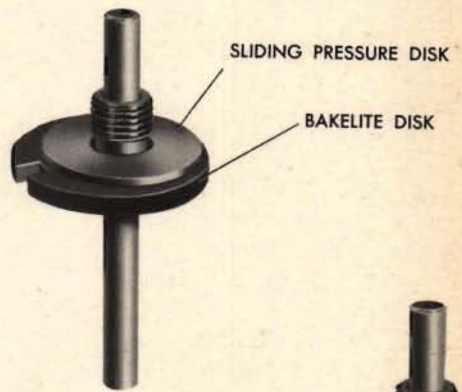
8 Pull the shaft with the pinned pressure disk out of the adapter.

Reassembling the unit

Holding friction

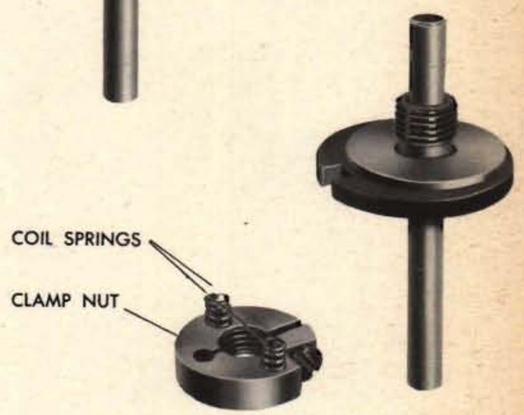


If the threaded hub has been removed from the shaft, repin it. The sliding pressure disk will not fit over the hub unless the ends of the pin are slightly below the surface of the threaded hub. Burrs raised by staking the pin must be removed.

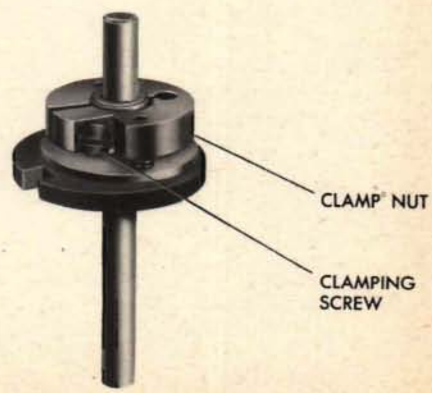


2 Mount the bakelite disk on the shaft and stud.

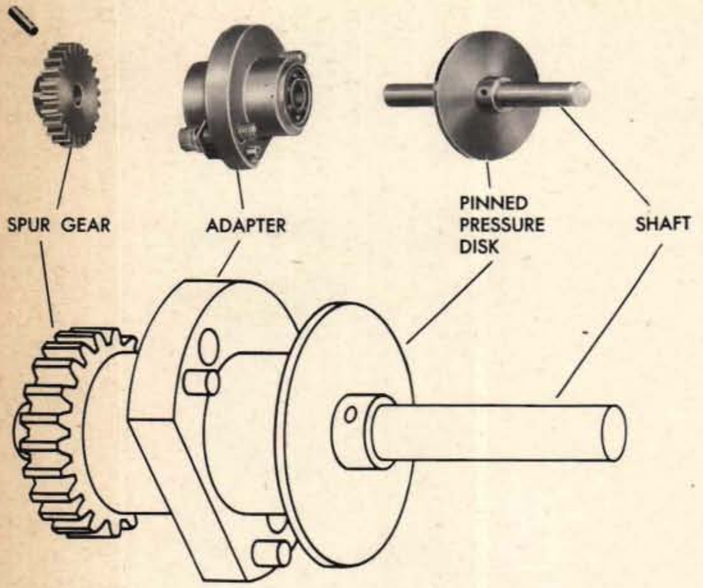
3 Replace the sliding pressure disk.



4 Apply a small amount of grease to the coil springs to hold them in the clamp nut while it is being assembled. Be careful not to get any grease on the disks.



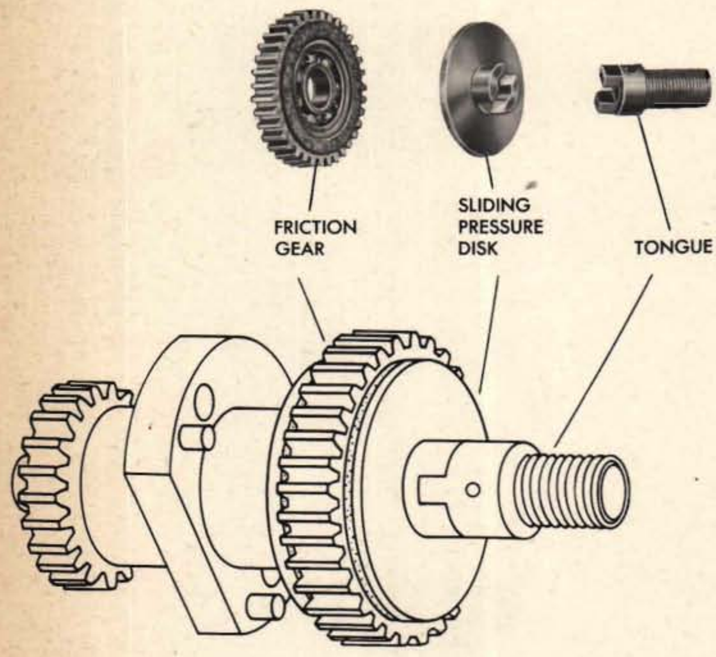
5 Screw the clamp nut down until the friction holds as recommended in the instrument OP. Tighten the screw.



Safety friction

1 Put the shaft into the adapter.

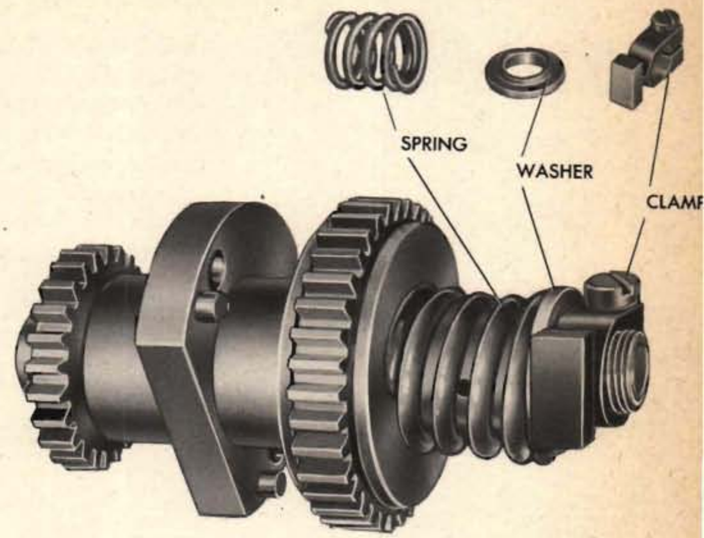
2 Pin the spur gear to the shaft.



3 Mount the friction gear on the shaft.

4 Replace the sliding pressure disk on the shaft.

5 Mount the tongue and pin it to the shaft.



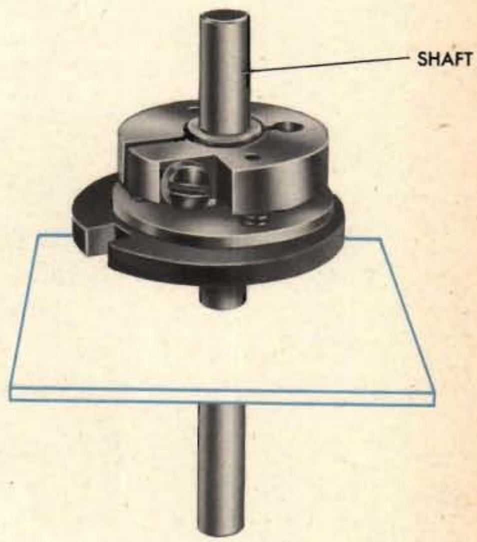
6 Replace the spring on the tongue.

7 Mount the metal washer with its flat surface toward the clamp end.

8 Replace the clamp.

9 Adjust the unit according to the directions given in the instrument OP.

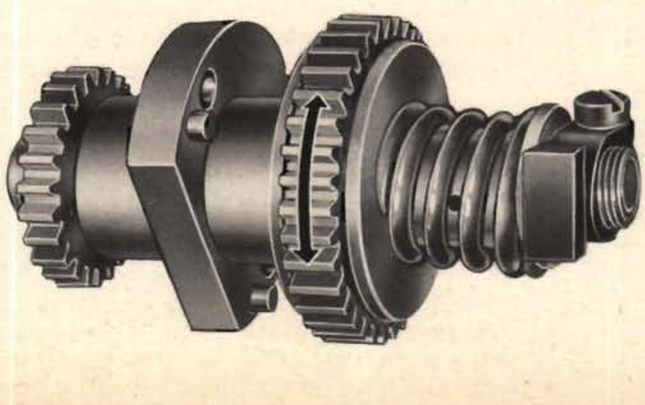
Bench checking the unit



The friction assembly should be checked before the unit is reinstalled in the instrument.

It should be possible to adjust the friction easily.

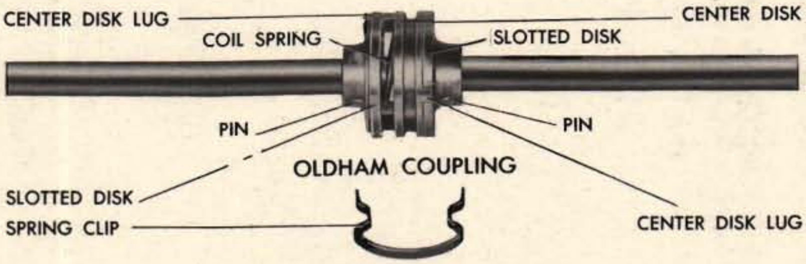
When the friction is tightened, it should turn smoothly by hand.



COUPLINGS

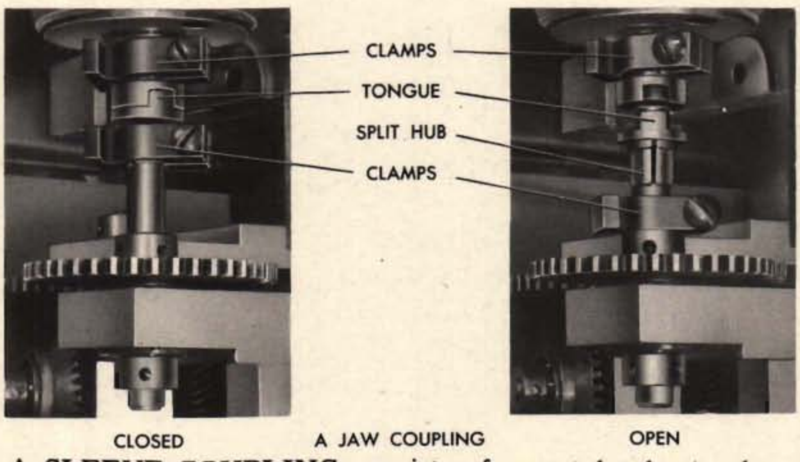
A coupling is a device which joins two shafts so that they function as one.

An OLDHAM COUPLING is used to compensate for lateral misalignment. It consists of two slotted disks, pinned with their faces flush with the ends of the shafts, and a center disk which has lugs that fit in the slots. A coil spring holds the center disk in position. A spacer in the form of a spring clip keeps the coupling from being opened by a severe shock. Another coupling, similar to the Oldham coupling in appearance, is used as an expansion joint, or for joining removable shafts. In this coupling, the shaft ends extend into the center disk and there can be no lateral misalignment.



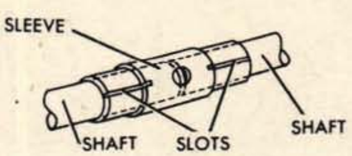
OLDHAM COUPLING

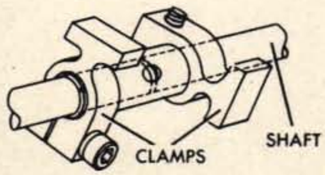
A JAW COUPLING, or CLUTCH, is made up of two parts, one with a tongue and the other with a mating groove. The split hub of each part is clamped to its respective shaft.



A JAW COUPLING

A SLEEVE COUPLING consists of a metal tube or sleeve which fits over the ends of the two joining shafts. It is slotted at both ends so that it can be clamped firmly on the shafts.





Whenever possible, a coupling should be repaired without disassembly. If disassembly is necessary, the instrument OP should be consulted, because shafts, hangers, and even units may have to be removed.

Typical symptoms

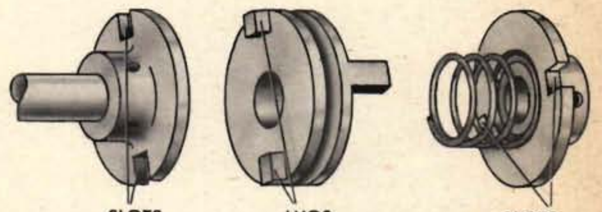
If a shaft line check indicates that a coupling is not functioning properly, look for one or more of the following typical symptoms:

STICKING: When the shaft is turned, it binds at one or more points or turns sluggishly.

EXCESSIVE LOST MOTION: There is too much play in the coupling.

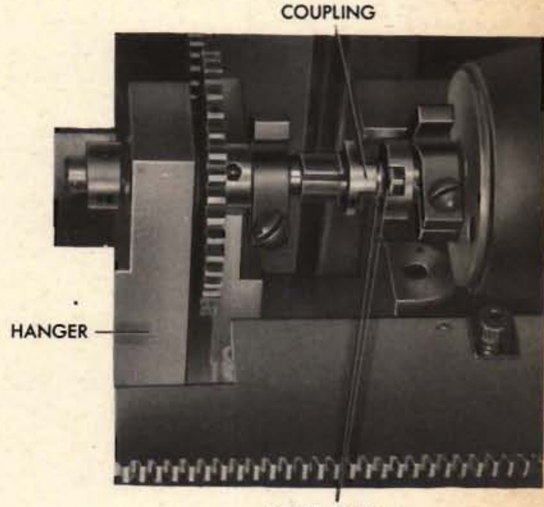
SLIPPING: One shaft moves intermittently when the other shaft is turned.

Locating the cause and repairing the parts



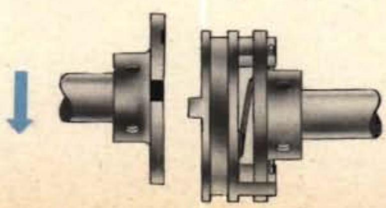
STICKING in a shaft line may be caused by chips between the mating surfaces which may cock the coupling, insufficient clearance between the ends of the shafts, or misalignment of the two shafts in excess of the allowable limit.

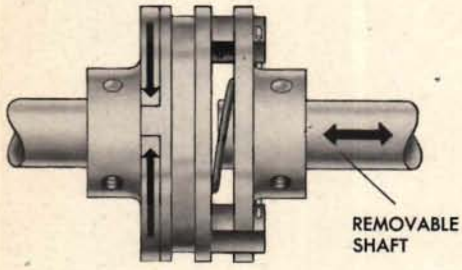
A burr on the mating surfaces of coupling tongues, grooves, lugs, or slots can be removed by filing or stoning. Be very careful not to cause excessive play by removing too much metal.



If, after a repair has been made, the shaft ends interfere at the coupling, reposition hangers in the gear train to relieve the interference. If this is impracticable, shorten the shafts, but only as a last resort.

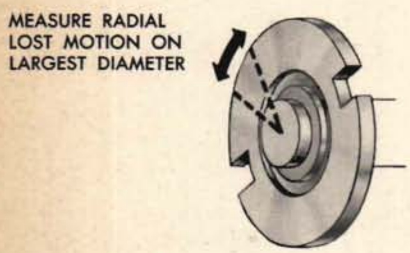
If two shafts joined by an Oldham coupling are misaligned beyond the allowable limit, this condition may be corrected by repositioning shaft assemblies or units. Be sure that the problem has been thoroughly investigated before making these repairs.



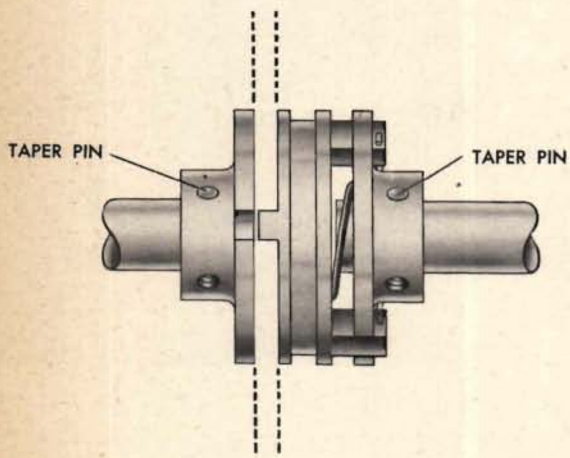


EXCESSIVE LOST MOTION may be caused by improper fitting of the coupling parts.

The angular lost motion through all the parts should not exceed the allowable limit measured on the largest diameter. Lost motion of this type has the same effect as lost motion between gears.



Excessive end play in a removable shaft may be reduced by repositioning the coupling disks or the shaft hangers. Where one of the disks is held to the shaft by a clamp instead of a pin, the disk may have been improperly positioned when the clamp was tightened. In such a case, reposition the disk by means of the clamp.

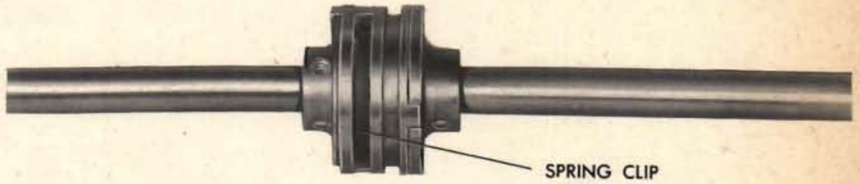


SLIPPING may result if there is too much clearance between the disks of a coupling or if a taper pin is sheared or missing. The parts between which there is too much clearance should be repositioned. A sheared taper pin should be replaced and the cause of the condition found and eliminated.

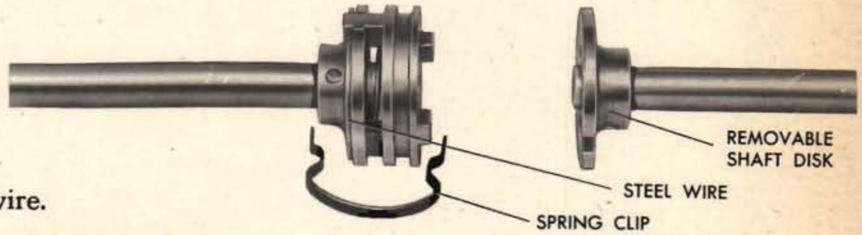
Disassembling and reassembling the unit

The following disassembly procedure for the coupling used on removable shafts will allow most repairs to be made and permit replacement of defective parts.

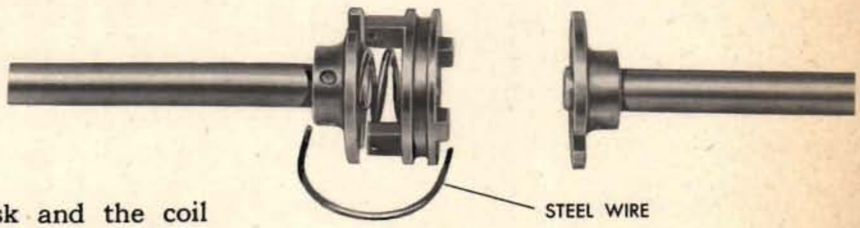
1 Remove the spring clip.



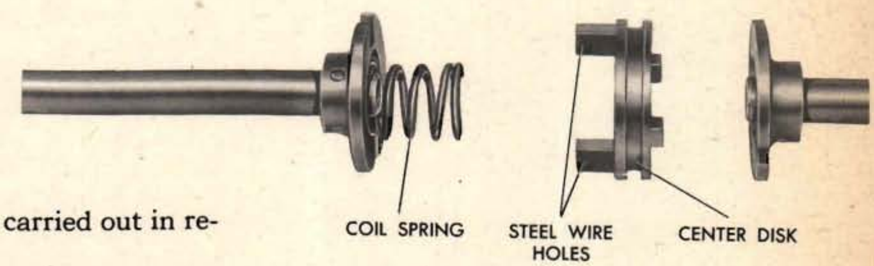
2 Disconnect the removable shaft.



3 Remove the bent steel wire.



4 Remove the center disk and the coil spring.



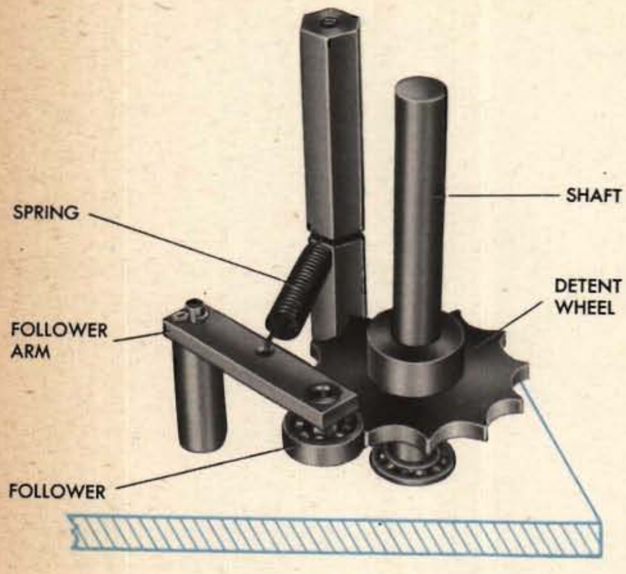
The same procedure can be carried out in reverse order for reassembly.

Bench checking the unit

The coupling should be reassembled to meet the allowance given on the assembly drawing.

There should be no excessive lost motion.

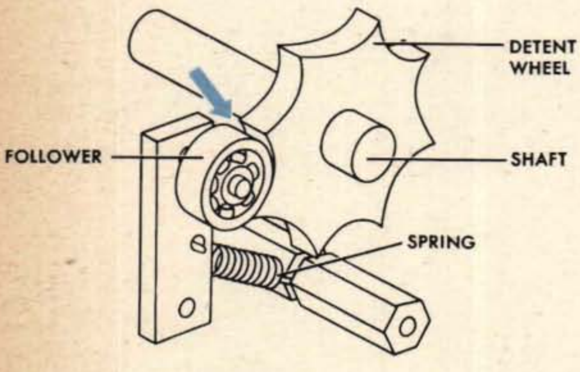
All moving parts of the coupling should be lubricated.



THE DETENT

A detent is used to hold a shaft firmly in one of several definite positions.

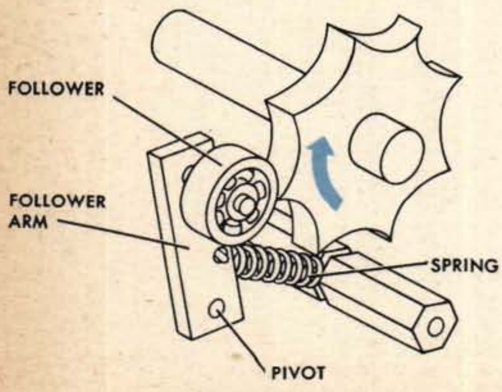
A detent consists of a specially shaped wheel fixed to a shaft, and a follower on an arm. The follower is held in the depressions of the detent wheel by a spring. The detent wheel is usually pinned to a shaft.



Locating the cause and repairing the parts

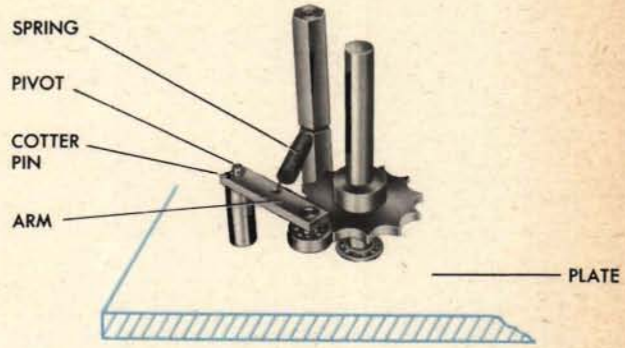
If a detent does not hold the shaft at exactly the proper position because the follower is not held securely in each depression of the detent wheel, look for a weak or loose spring, a dirty or damaged bearing, a faulty pivot, or a bent follower arm.

A weak or loose spring can be replaced without disassembling the unit. To make a new spring, wind a piece of music wire to fit the specifications of the assembly drawing. If necessary, a spring having the last coil broken or damaged can be repaired.



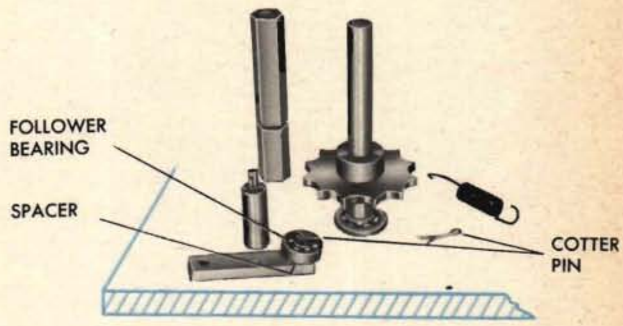
To detect a faulty bearing on the follower, turn the detent wheel by hand. The movement of the follower as it goes across the high point and into the depression will feel rough if a bearing or pivot is dirty or damaged. To replace a faulty bearing or pivot the unit must be disassembled. It must also be disassembled to straighten a bent follower arm.

Disassembling the unit

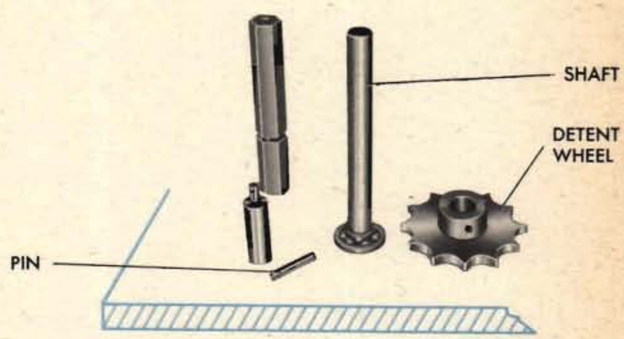


1 Unfasten the spring from the arm.

2 Remove the cotter pin in the pivot and lift the arm off the pivot.



3 Remove the cotter pin and spacer and pull off the follower bearing. Do not lose the spacers; they position the follower with respect to the detent wheel.



4 Tap out the pin holding the detent wheel to the shaft.

Reassembling the unit

In reassembling the unit, follow the disassembly procedure in reverse. Be sure to replace the spacers so as to line up the detent teeth with the follower.

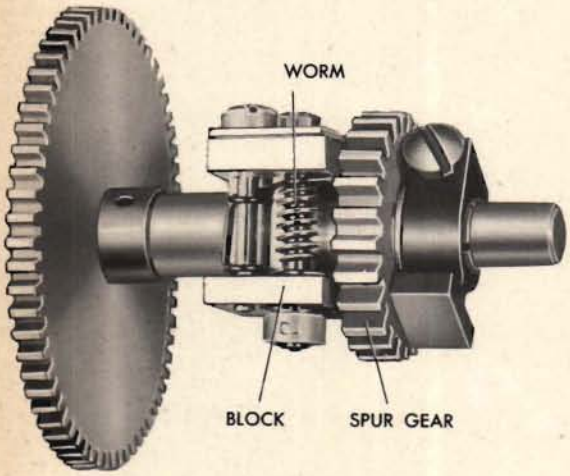
Bench checking the unit

The follower and detent wheel should be in full mesh. The shaft to which the detent wheel is pinned should turn freely when the follower is disengaged. When the follower is engaged, it should click sharply into each depression in the detent wheel as the shaft is turned.

THE VERNIER CLAMP

A vernier clamp is used to make a fine adjustment in the position of a gear on a shaft.

A vernier clamp consists of three parts: a sleeve, a spur gear, and a block. The sleeve usually has an ordinary clamp to hold it to the shaft. The gear fits over the sleeve and can be turned on it. The spur gear is pinned on a worm gear hub. The block is pinned to the sleeve and holds a small worm that meshes with the worm gear. There is a slot in one end of the worm so that it can be turned by a screw driver. When the worm is turned, the worm gear and shaft turn with respect to the shaft. A locking screw holds the worm in position after the adjustment has been made.

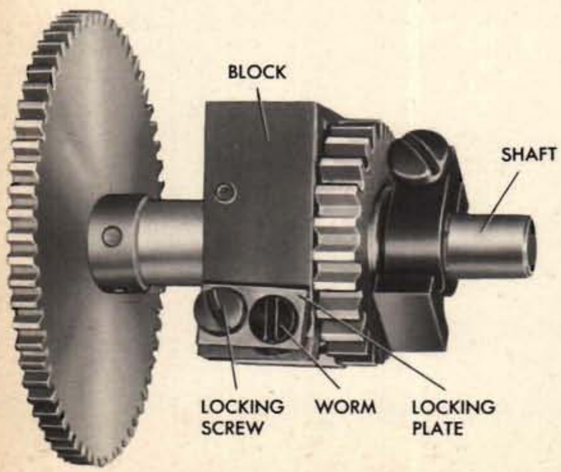


Typical symptoms

JAMMING OR STICKING: The gears freeze or stick on the sleeve.

EXCESSIVE LOST MOTION: There is too much play between the worm and the spur gear.

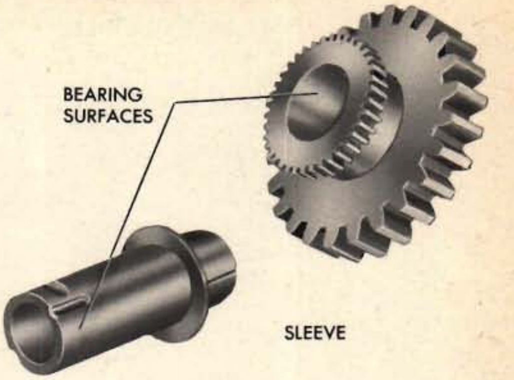
SLIPPING: When the shaft is turned, the vernier clamp is not carried around with it, or adjusting the worm does not turn the gear.



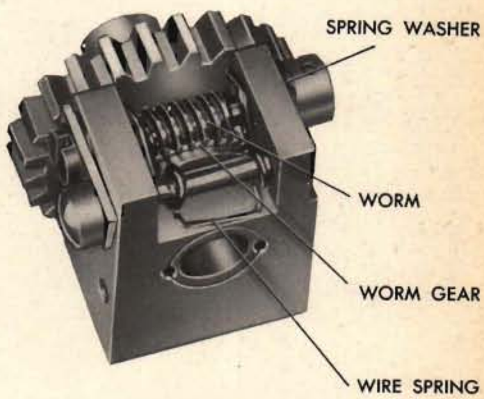
Locating the cause and repairing the unit

If the head of the locking screw is burred, it may be difficult to adjust the screw or to make it hold after it has been adjusted. Replace the locking screw, or repair it by filing a deeper slot in the head and smoothing the burred edges.

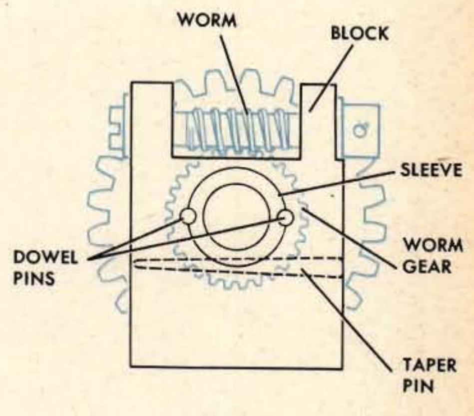
JAMMING OR STICKING of the worm may occur because of damaged worm threads or worm gear teeth; or because of dirty, burred or rough bearing surfaces on the sleeve or in the spur and worm gear assembly. To free the spur and worm gear assembly so that it can be turned on the sleeve, smooth the sleeve, using a very fine abrasive to remove just enough metal to even out the high spots. If too much metal is removed, the assembly will fit too loosely on the sleeve. Clean and lubricate the parts and reassemble the unit.

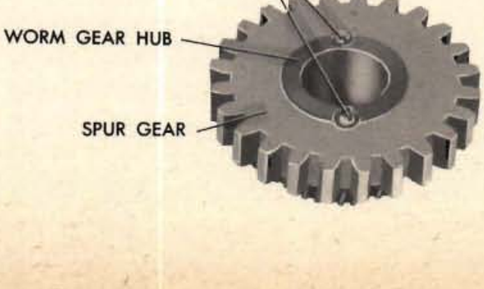


EXCESSIVE LOST MOTION between the spur gear and the shaft may be caused by a damaged worm or worm gear, by a weak or broken wire spring, or by a weak spring washer. The unit must be disassembled to replace a damaged worm or to replace a spring washer which does not take up the lost motion.

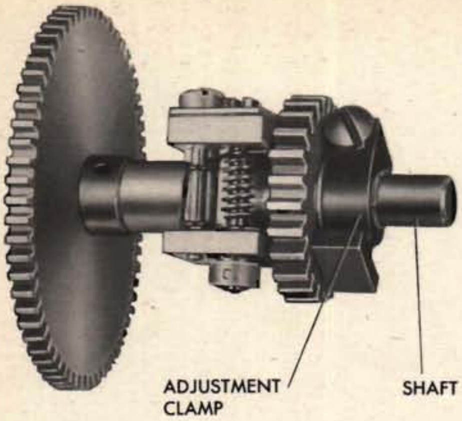


SLIPPING of the spur gear with respect to the shaft may result if the dowel pins which secure the spur gear to the worm gear hub are sheared; or if the taper pins securing the sleeve to the block are sheared. The unit must be partially disassembled to replace worn or damaged parts. For instructions on replacing pins, refer to the section on doweling, pages 74-75.

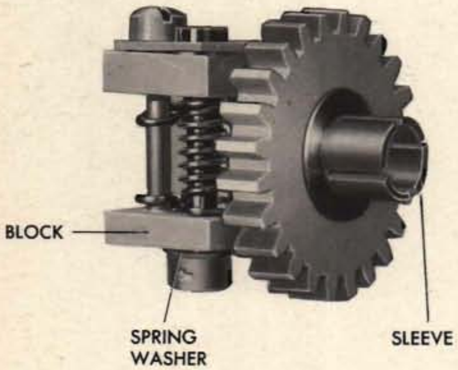




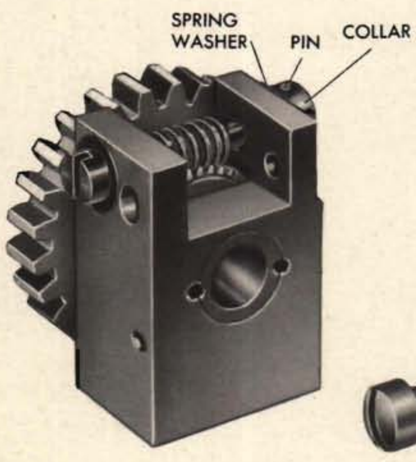
Disassembling the unit



1 Remove the adjustment clamp.

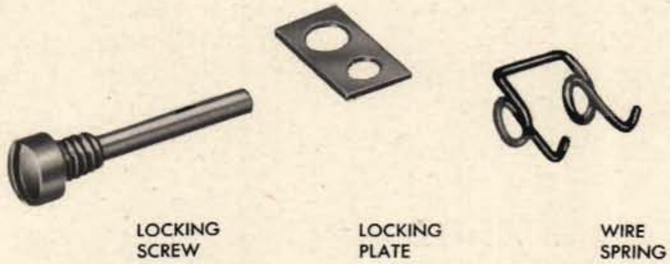


2 Slide the sleeve and block off the shaft.



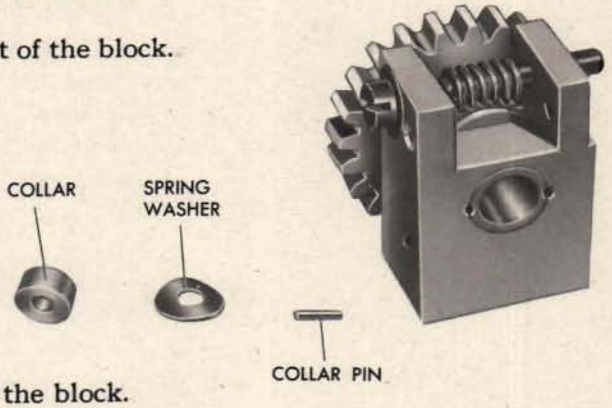
3 Remove the locking screw, the metal locking plate, and the wire spring.

4 Drive the pin out of the small collar.

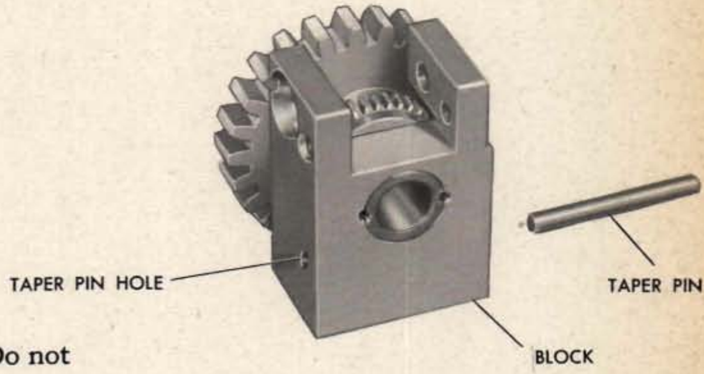


5 Lift off the collar and spring washer.

6 Carefully pull the worm out of the block.

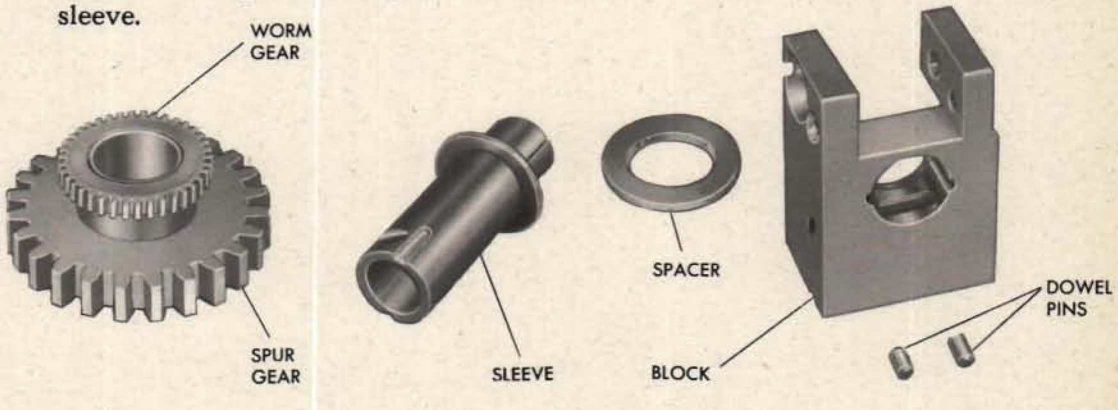


7 Drive the taper pin out of the block.



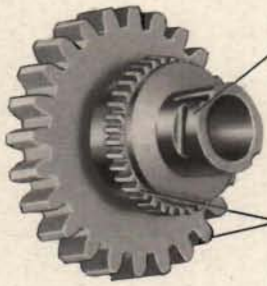
8 Drive the sleeve out of the block. Do not lose the two dowel pins.

9 Remove the spacer and gears from the sleeve.



Reassembling the unit

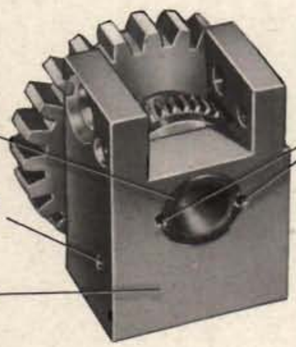
Lubricate all parts before reassembly. In reassembling the unit, be careful to eliminate all excessive lost motion.

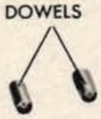


1 Mount the gears and spacer on the sleeve.

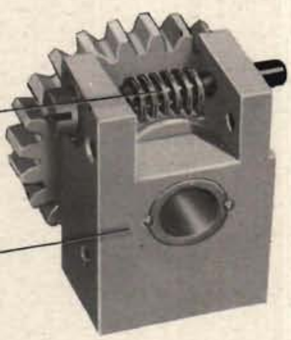
2 Push the sleeve into the block and pin the block and sleeve together with the two dowels and the taper pin. Stake all three pins.

3 Mount the worm in the block.



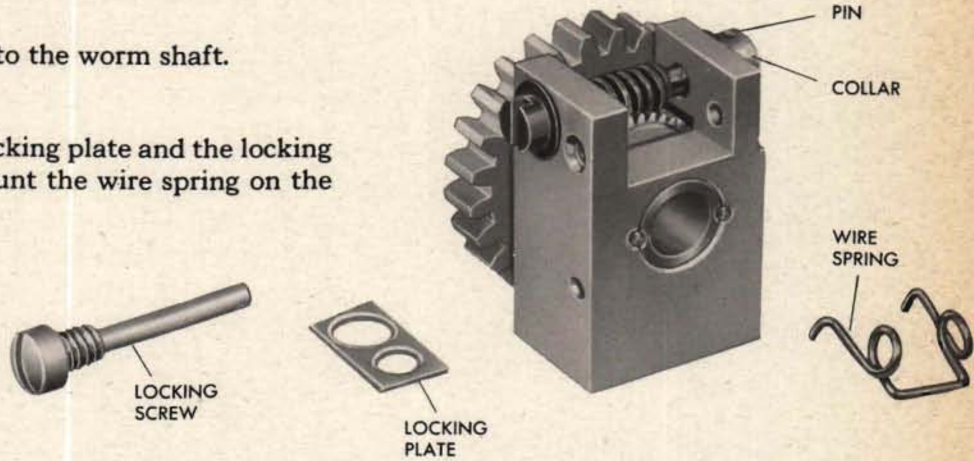


4 Mount the spring washer and collar on the worm shaft.



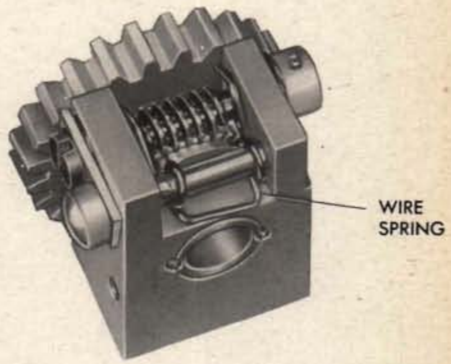
5 Pin the collar to the worm shaft.

6 Replace the locking plate and the locking screw, and mount the wire spring on the screw.



7 Slide the assembled parts on the shaft.

8 Mount the adjusting clamp and tighten it.

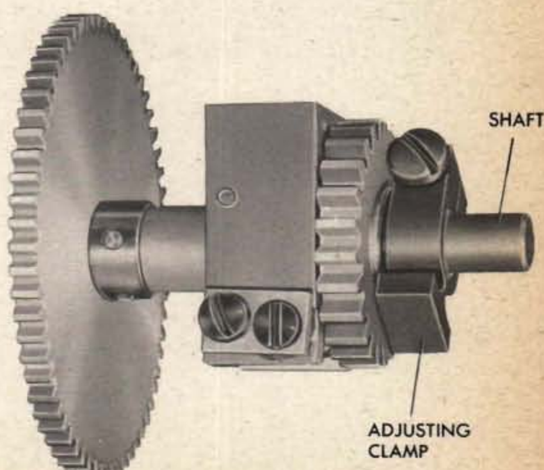


Bench checking the unit

Be sure that there are no damaged gear teeth.

Turn the worm to check that the movement of the spur gear is smooth without excessive lost motion. When the locking screw is tightened, the locking plate should hold the worm securely in position.

The wire spring should press down firmly on the worm shaft to take up any looseness in the plain bearings.



THE TAKE-UP SPRING

METAL-RIBBON TAKE-UP SPRING

A take-up spring is a coiled length of wire, or a metal ribbon like a clock spring, mounted in a shaft line. Its purpose is to take up lost motion in the shaft line.

The wire spring is usually wound around a shaft, with one end clamped to the shaft and the other hooked to a post on a hanger.

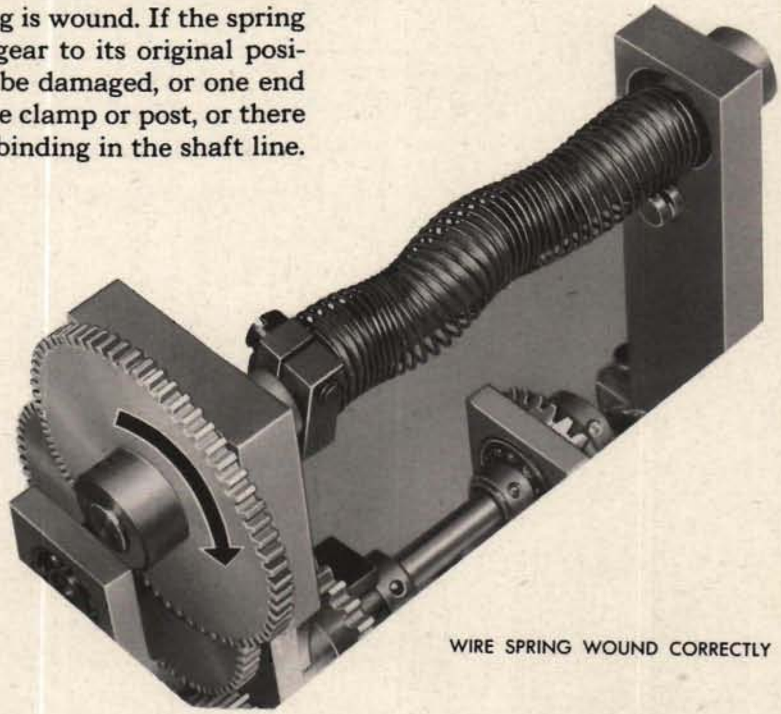
WIRE TAKE-UP SPRING

To adjust the take-up spring, consult the instrument OP.

CAUTION:
Do not wind the spring too tightly, or wind it backward. If there is sticking in the shaft line which prevents the spring from taking up lost motion, locate and eliminate the trouble. Do not attempt to compensate by winding the spring too tightly.

Locating the cause and repairing the parts

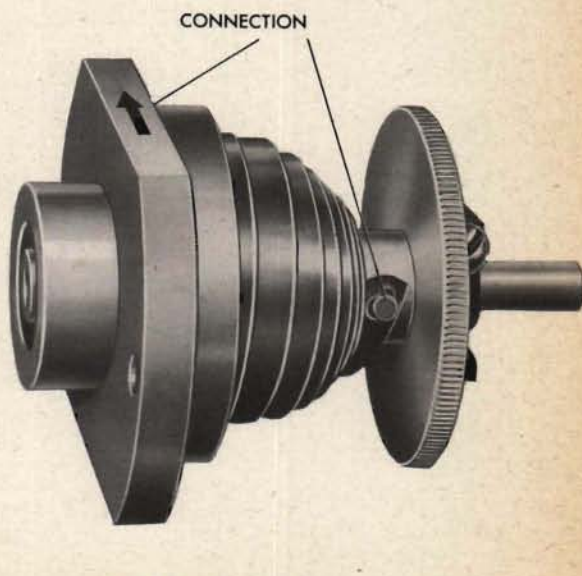
With the instrument power OFF, turn the largest gear in the shaft line in the SAME direction that the spring is wound. If the spring does not return the gear to its original position, the spring may be damaged, or one end may be loose from the clamp or post, or there may be a sticking or binding in the shaft line.



WIRE SPRING WOUND CORRECTLY

A metal-ribbon spring wound backward may unhook or snap at the points where it is connected.

To repair a wire spring broken at the post or the clamp, use long-nosed pliers. Without kinking the wire, bend the end of the spring to make a new hook. Replace a damaged spring. Consult the instrument OP before rehooking a metal-ribbon spring to the case.



METAL-RIBBON SPRING

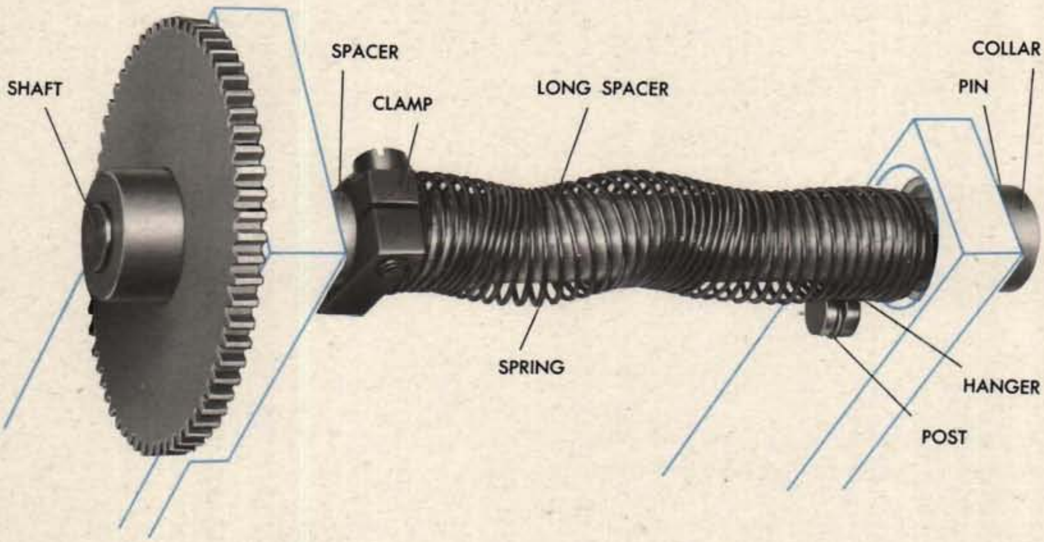
Disassembling a wire spring

1 Loosen the clamp.

2 Drive the pin out of the collar and remove it from the shaft.

3 Loosen the hanger screws and pull off the hanger, the spring, the clamp and the long spacer.

4 Unhook the spring from its post and unhook the clamp from the spring.



Reassembling a wire spring

1 Slide the clamp and the long spacer on the shaft.

2 Draw the spring over the spacer and hook it to the clamp.

3 Push the hanger on the shaft and secure it to the plate.

4 Hook the spring to the post.

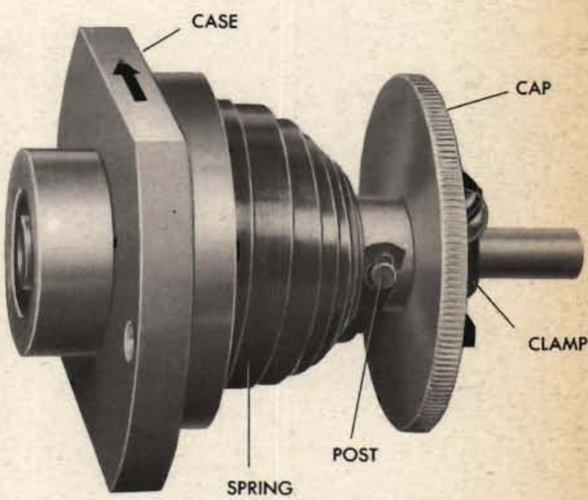
5 Pin the collar to the shaft.

Disassembling a metal-ribbon spring

1 Loosen the clamp and pull the cap up just enough to enable the spring to be unhooked from its post.

2 Unhook the spring from the post inside the case.

3 Loosen the case and pull the case and spacer off the shaft.



Reassembling a metal-ribbon spring

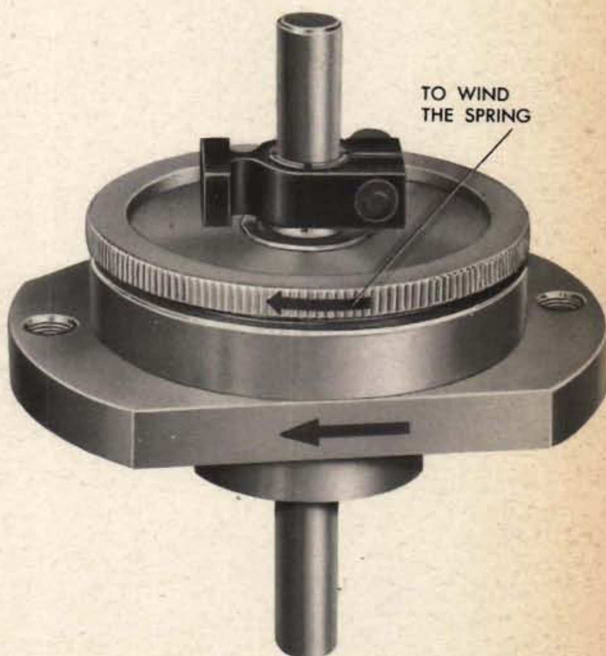
1 Mount and secure the case on the plate.

2 Hook the spring to the post in the case. The arrow on the case indicates the direction in which the spring should spiral from the post in the case.

3 Replace the spacer.

4 Mount the cap and hook the spring to its post.

5 Place the clamp on the split hub of the cap.

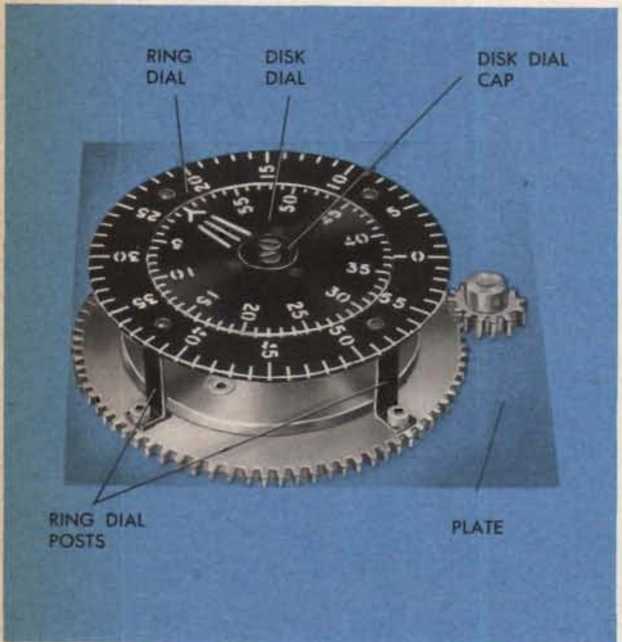


Checking the units

Check that the spring takes up the lost motion in its shaft line when the spring is wound according to the instructions given in the instrument OP.

Check that there are no kinks or crimps in the spring and that the coils are uniform in appearance.

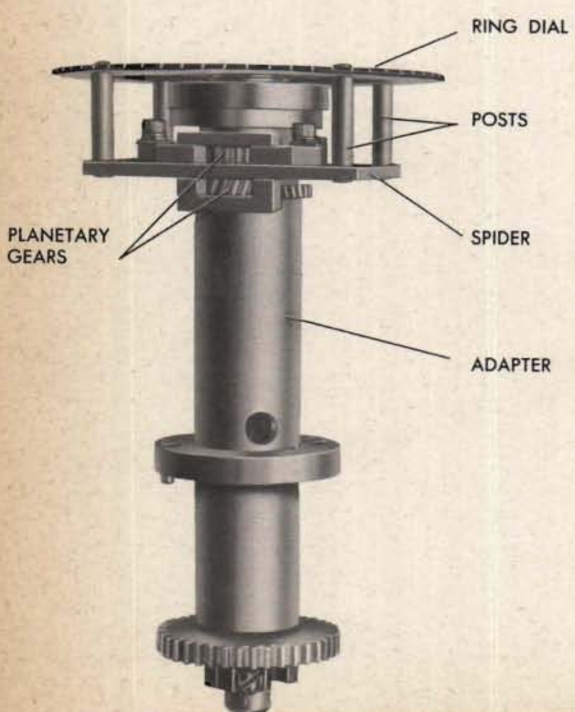
DIAL ASSEMBLIES AND COUNTERS



DIAL ASSEMBLIES

Dial assemblies are usually mounted in accessible parts of the instrument. They may be attached to shafts which are parts of other larger units, or they may be mounted on plates. Repairs can often be made without removing the assembly from the instrument. *Consult the instrument OP before attempting any repairs.*

There are two kinds of dials: disk and ring dials. A disk dial is held to a shaft between a hub on the shaft and a cap screwed to the hub. A ring dial is usually mounted on posts. The ring dial posts may be mounted on a planetary reduction gear spider.



Typical symptoms

If a dial assembly is not operating properly, look for one or more of the following typical symptoms:

JAMMING: The shaft, gear or spider supporting the dial cannot be turned by hand.

STICKING: The shaft, gear or spider supporting the dial resists moving past a certain point or points.

EXCESSIVE LOST MOTION: There is excessive play in the dial assembly gearing.

SLIPPING: The dial slips with respect to its hub, or the gearing supporting the dial slips with respect to the input shaft or gear.

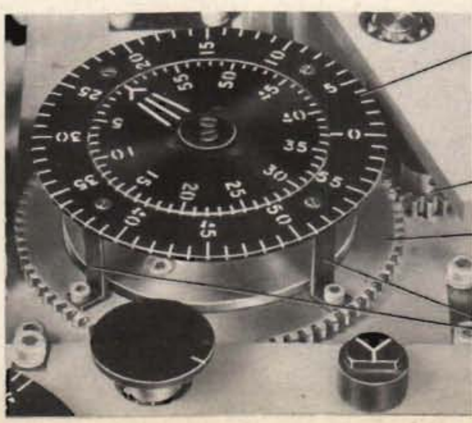
Locating the cause

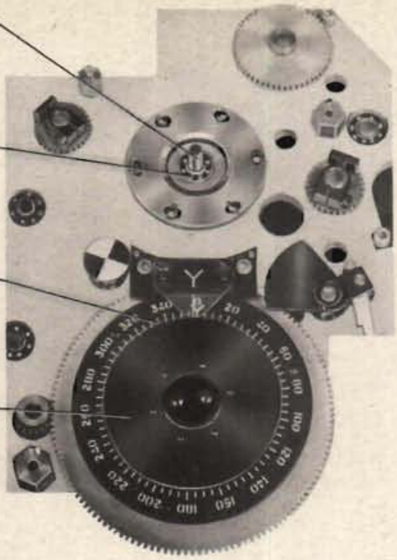
Jamming or sticking

Jamming or sticking of the dial against the mask, the mask lip, the index or the index block may be caused by a bent dial, a bent disk dial shaft, or a bent ring dial post.

Jamming or sticking may also be caused by dirty or damaged gears or bearings, frozen retainer balls, or a damaged race.

A ring dial may jam or stick because of interference between adjoining parts and the large gear on which it is mounted.

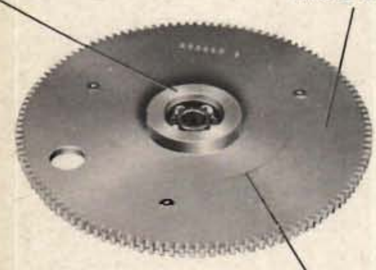


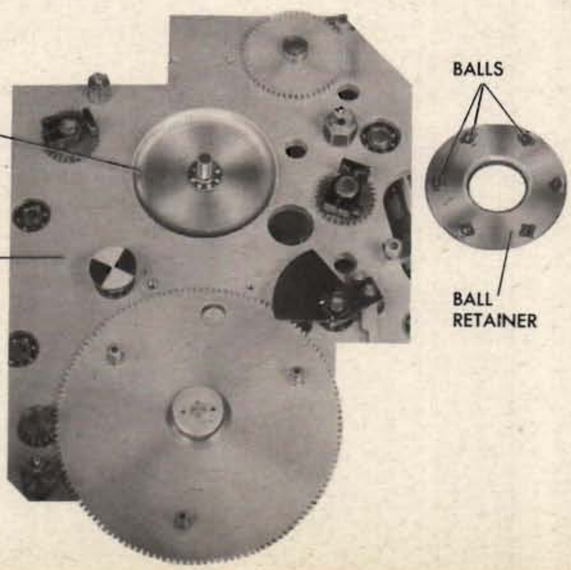


If a disk dial jams or sticks, inspect the paint at the edges of the dial for signs of wear. If the paint is worn off, probably the shaft on which the dial is mounted is bent. If the paint is not worn, the trouble may be a dirty or damaged bearing or gear on the shaft line. Make sure that the dial itself is not bent. Disassembly of the unit and removal of the shaft are necessary in order to repair or replace dirty or damaged parts.

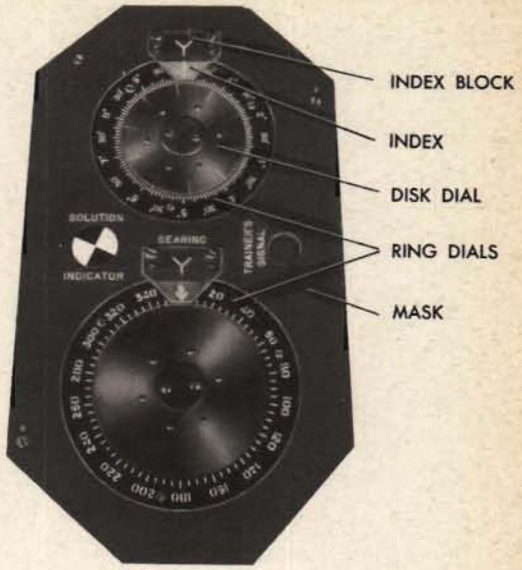
If a ring dial jams or sticks, inspect its edges for worn off paint. If the paint is worn off, the posts on which the dial is mounted may be bent; or the ring dial may be shifted within the clearance holes and secured in the wrong position relative to the mask and disk dial.

The ball races in the plate recess and on the gear may also be worn or damaged. An excessively worn race on the plate or gear will allow the gear hub to rub against the plate.



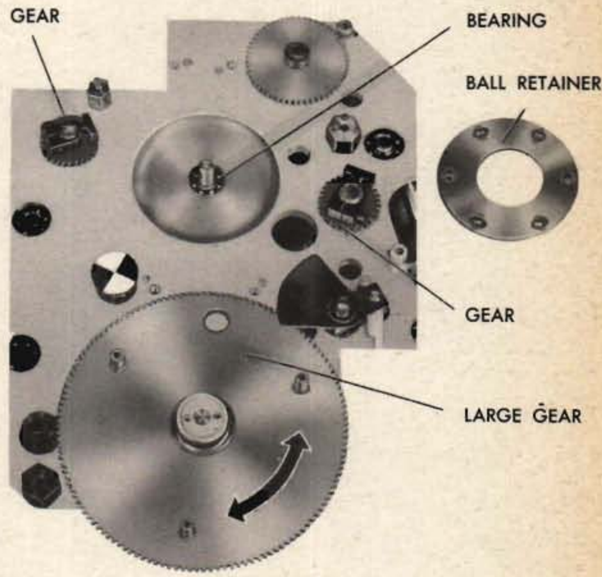


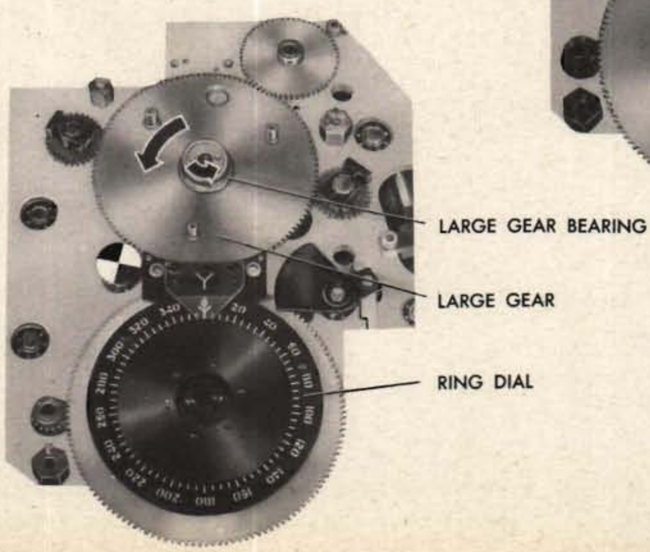
Inspect the ring dial to see whether or not it is bent. A bent dial can often be straightened. A loose dial can usually be secured by tightening the three post screws. Make sure that the mask, index, and index block are mounted so that the dials turn freely and without rubbing. In order to straighten, repair, or replace damaged parts, the unit must be disassembled.

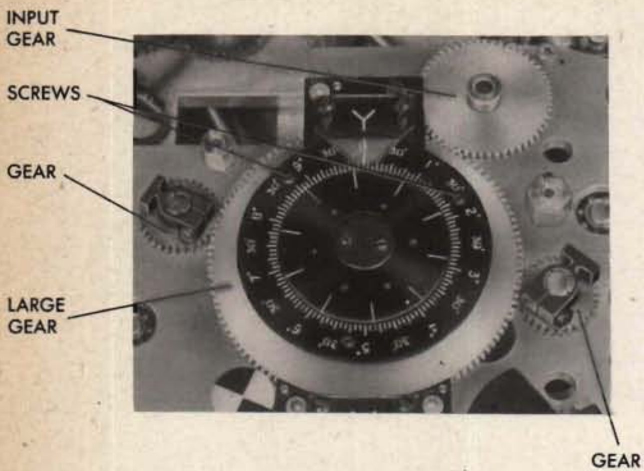


If the paint on the ring dial edges is not worn off, remove the dial and try to turn the large gear by hand. If it jams or sticks, disassemble the unit and look for damaged gear teeth or bearings, or balls frozen in the retainer. Clean and repair the parts and free any frozen bearings.

In the dial group shown in the accompanying illustrations, the ring dial is not geared to its corresponding disk dial; hence it turns independently. If the center shaft tends to turn with the large gear when the latter is turned, the bearing in the center of the large gear is probably dirty or damaged. A dirty bearing must be cleaned and a damaged one replaced.





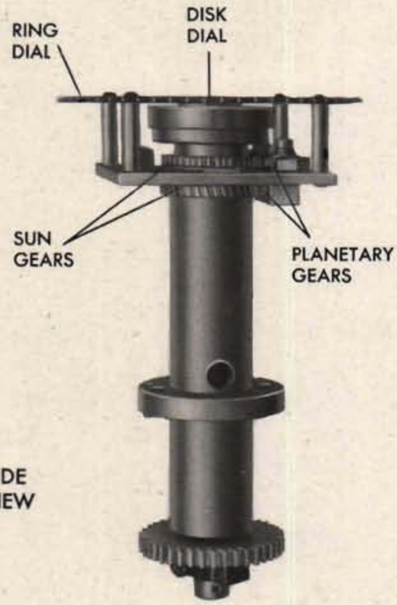


Excessive lost motion

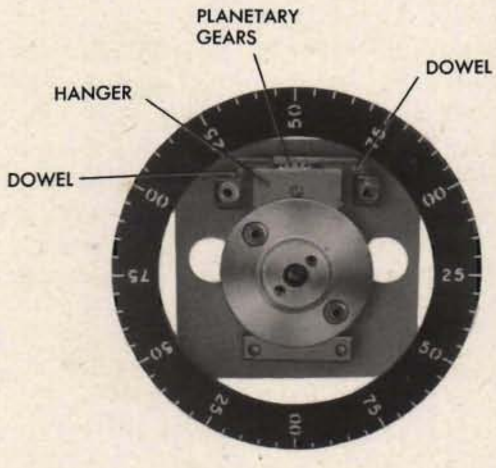
Excessive lost motion between the input gear and the dial may be caused by worn gear teeth, improper meshing of gears, or by a loose dial.

Make sure that all gears mesh properly. Clean dirty gears and replace worn ones. Secure a loose dial by tightening the screws which hold it to its mounting.

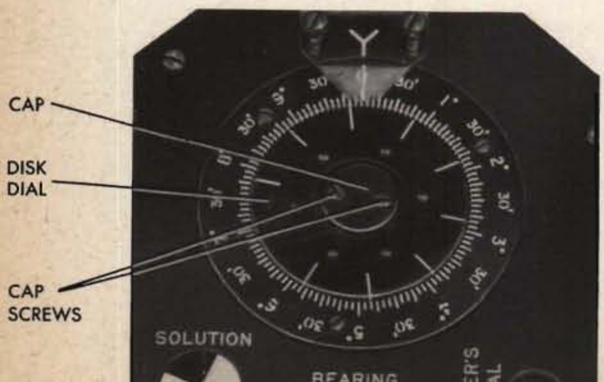
In a planetary-type dial unit, a lag between the fine and coarse dials is usually caused by excessive lost motion between the planetary gears and the sun gears. In order to reduce such lost motion, reposition the planetary gears by moving the hanger. Redowel the hanger with oversize dowels.



SIDE VIEW



TOP VIEW

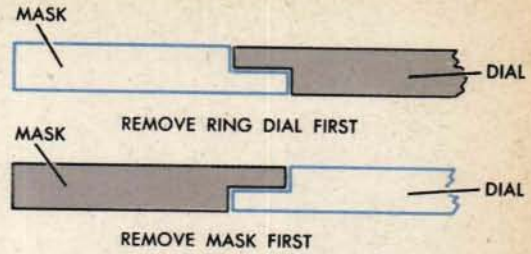


Slipping

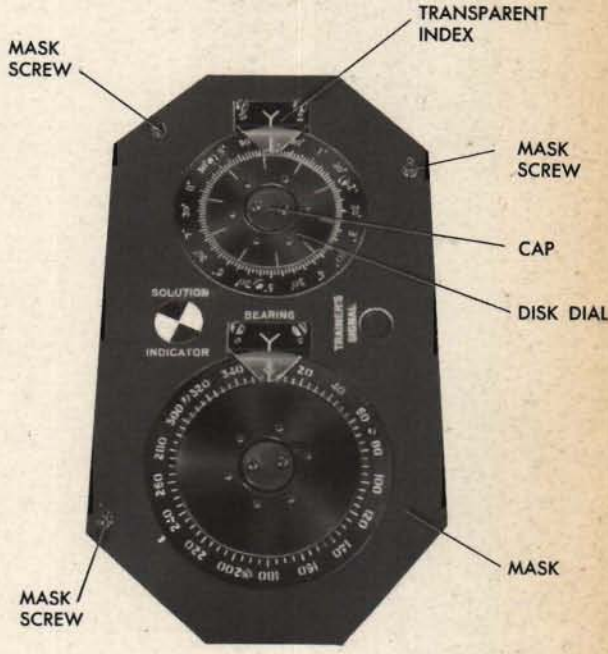
A disk dial may slip if the screws holding the cap to the hub are too long. Make sure that the dial cap is fastened with screws of the length specified by the assembly drawing. Screws that are too long will bottom before they clamp the dial between the cap and the hub. Tighten cap screws carefully in order to avoid burring the slots or shearing the heads.

Disassembling the unit

Many repairs require only partial disassembly. If complete disassembly is necessary, first consult the instrument OP. If possible, avoid removing the dial assembly from the instrument. The mask and the ring dials of some units have lips which make it necessary to remove one before the other.



The fine and the coarse dial assemblies have similar parts. When disassembling both dial assemblies at the same time, tag the parts to keep them separate.



1 Remove the mask. (The index assembly may be doweled to the base plate or to the mask.)

2 Remove the transparent index from the fine dial assembly.

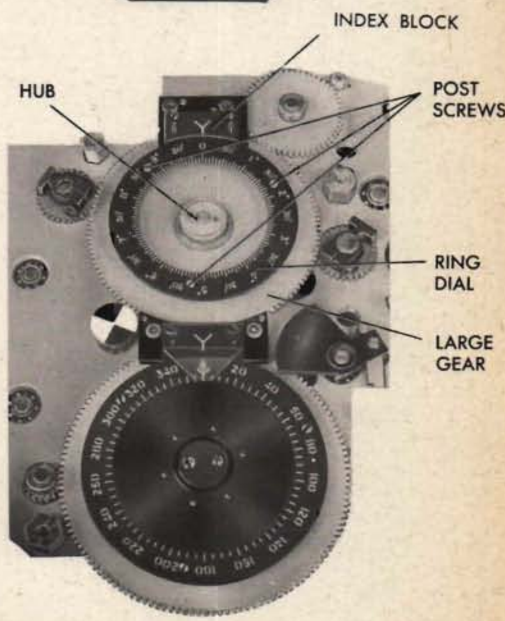
3 Remove the cap and the disk dial.

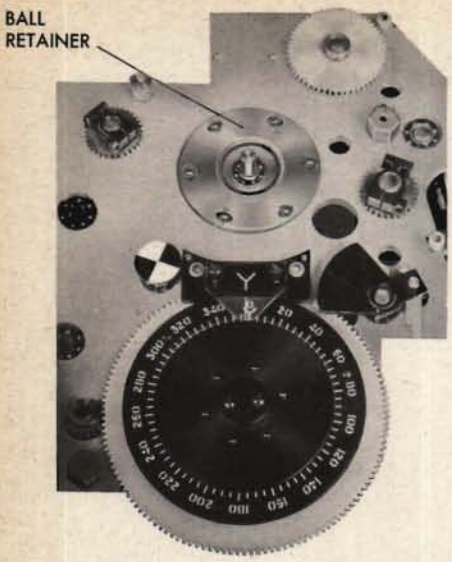
4 Remove the fine ring dial from the posts.

5 Remove the index block.

6 Drive the taper pin out of the hub. Back up the hub to prevent bending the shaft. *Tag the pin and hub taken from the fine dial assembly.*

7 Remove the large gear with three posts from the shaft.





8 Lift out the ball retainer.

9 Follow the same procedure in disassembling the coarse dials.

Disassembling the synchro transmitter dial

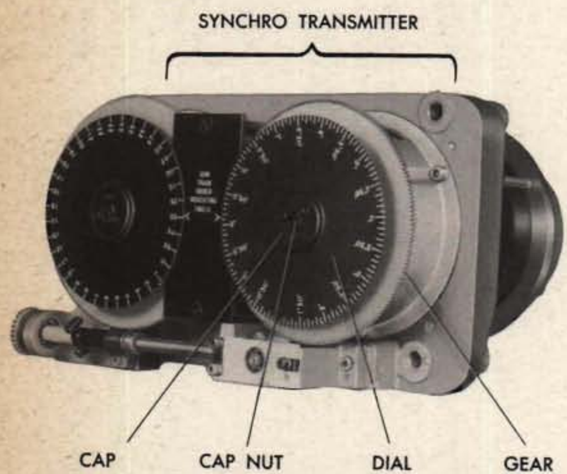
In synchro transmitter dial assemblies, the dial is clamped on one end of a gear hub which is secured to the synchro shaft by a cap nut and Woodruff key. The cap nut is slotted to receive a screwdriver.

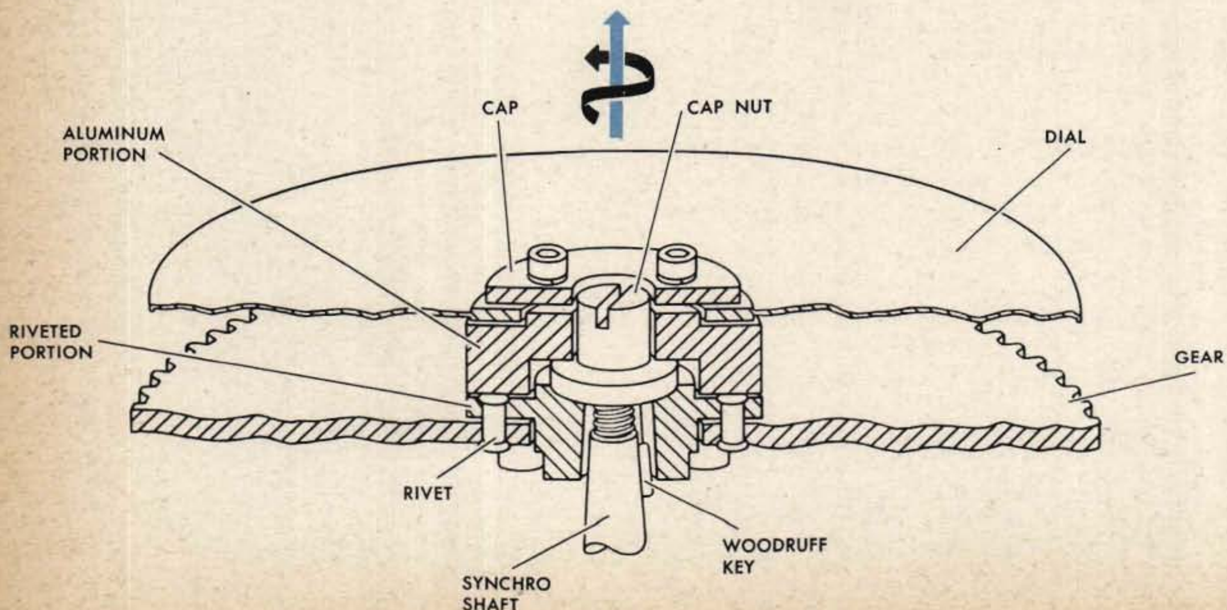
1 While holding the gear turn the cap nut counterclockwise to "jack" the entire dial assembly off the synchro shaft.

2 Remove the cap from the hub in order to lift off the dial. (The dial may be removed while the hub is still on the synchro shaft).

3 Separate the aluminum portion of the hub from the portion riveted to the gear in order to remove the cap nut.

REASSEMBLE a synchro transmitter dial assembly by reversing the disassembly procedure.

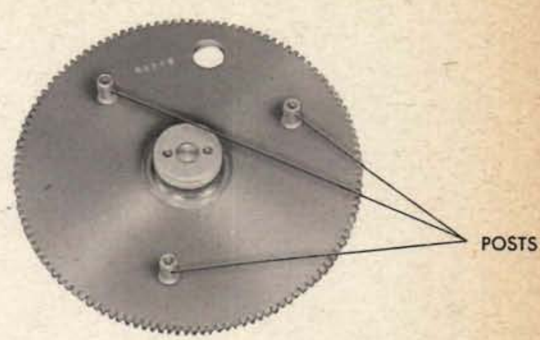




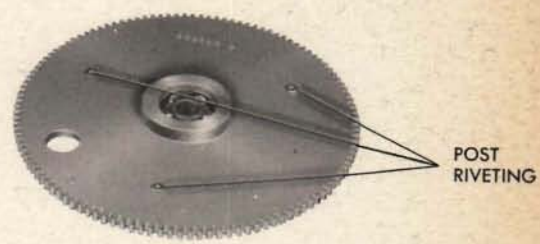
Repairing the parts

The method of repairing dials depends on the type of dial and the material from which it is made.

LARGE GEAR
TOP VIEW

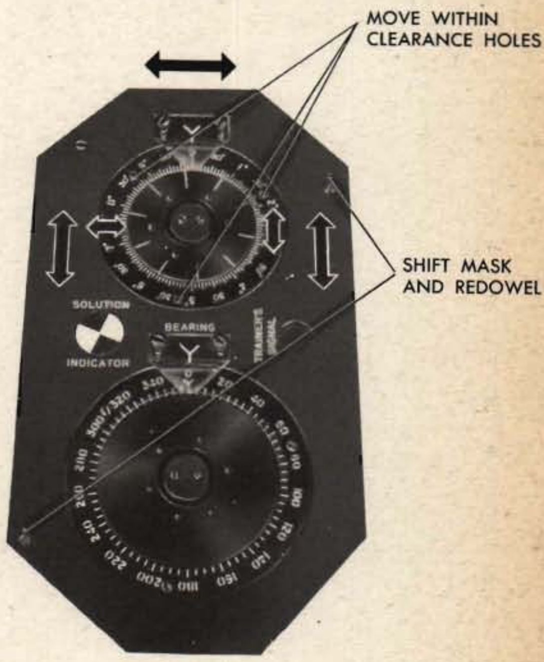


Dials may be made of aluminum or plastic. Graduations may be engraved on the dial or printed photographically. Some aluminum dials have punched out graduations.



LARGE GEAR
BOTTOM VIEW

A bent dial can usually be straightened in place. If a dial is badly bent, however, place it on a small anvil and tap it into shape with a small plastic hammer. Protect the painted surfaces while tapping.

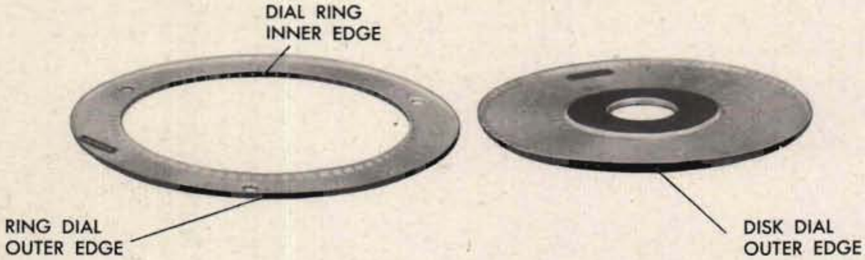


If a ring dial does not run true and rubs against a mask, the dial may have shifted within the screw clearance holes. In order to reposition the dial, loosen the screw and shift the dial until it runs true and clears both the mask and the disk dial.

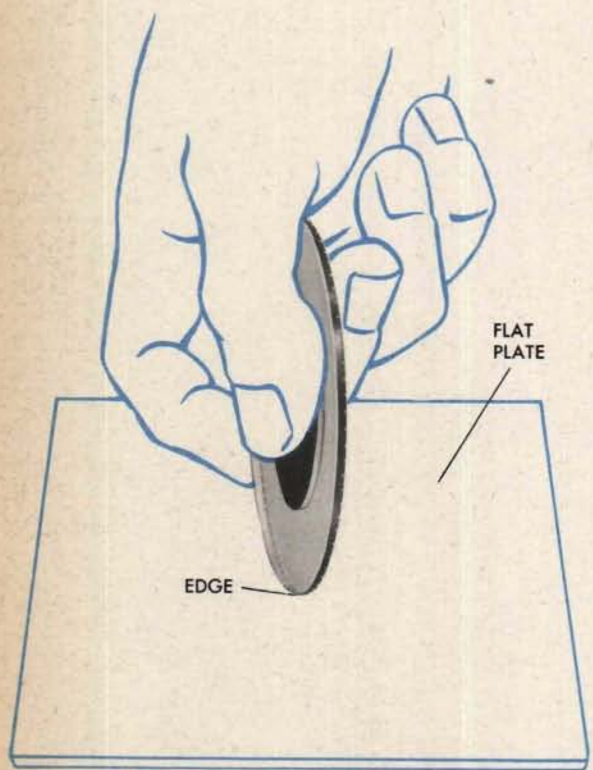
If a dial rubs against one portion of a mask, regardless of the value at which the dial is set, the mask should be shifted until the dial clears. Masks usually are doweled, so the dowels must be removed before the mask can be shifted. Redowel the mask in its new position, using oversize dowels.

Replacing a dial

If a dial has to be replaced, be sure that the new dial has the same part number. This is usually stamped on the back of the dial.



A new aluminum dial which has punched-out graduations may rub against a mask or against an adjacent dial because the edges flare out too much. An outer edge can be "rolled under" a few thousandths of an inch by pressing and rolling the dial on a smooth flat plate. Be very careful not to bend the dial out of shape or chip the paint.



ROLLING AN EDGE UNDER

Too much paint on the edge of a new dial may cause the dial to rub. Remove any excess paint with fine abrasive paper.

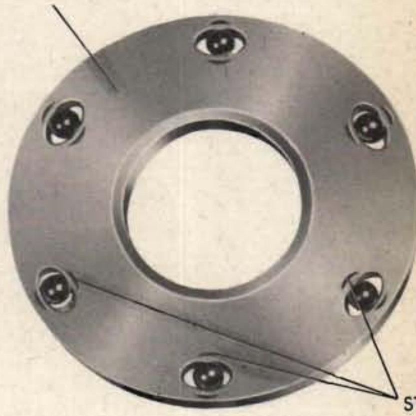
Painting a dial

Be sure to use the right kind of lacquer to paint the damaged surface or graduations of a dial.

CAUTION:
Do not use lacquer thinners on photographic dials.

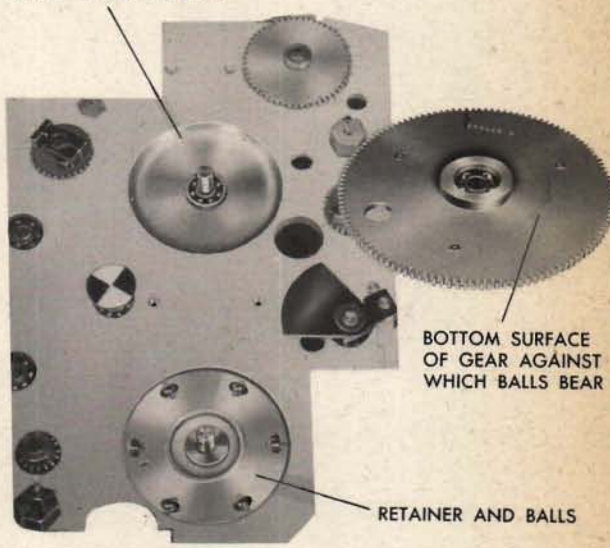
Repairing a ball retainer

If a ball does not spin freely in the retainer, remove it and enlarge the hole with a fine jeweler's file. Then polish the hole, but *do not polish the ball*. Replace the ball and secure it by staking each side of the hole. Lubricate the ball retainer.



Polishing the plate and gear surfaces

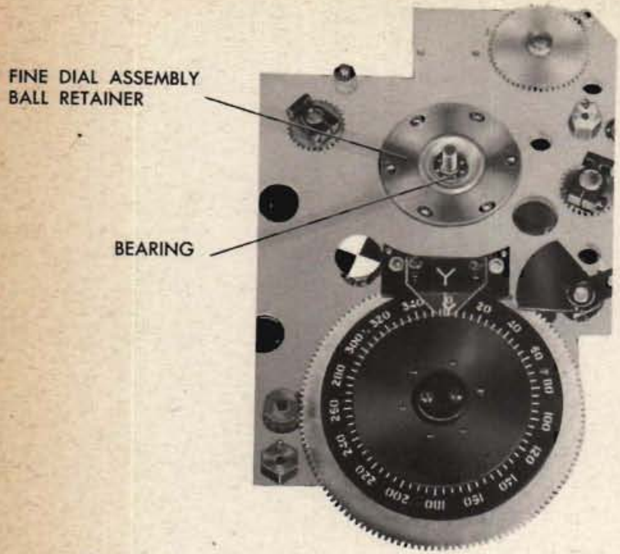
Pits or grooves in the plate can sometimes be removed by using a fine abrasive paper and then polishing the plate. A pitted gear surface can sometimes be polished smooth. Before reassembly, clean the retainer and the plate and gear surfaces with a suitable solvent.

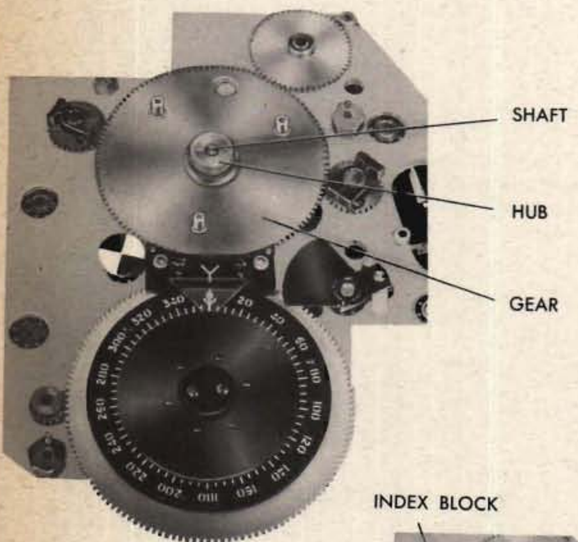


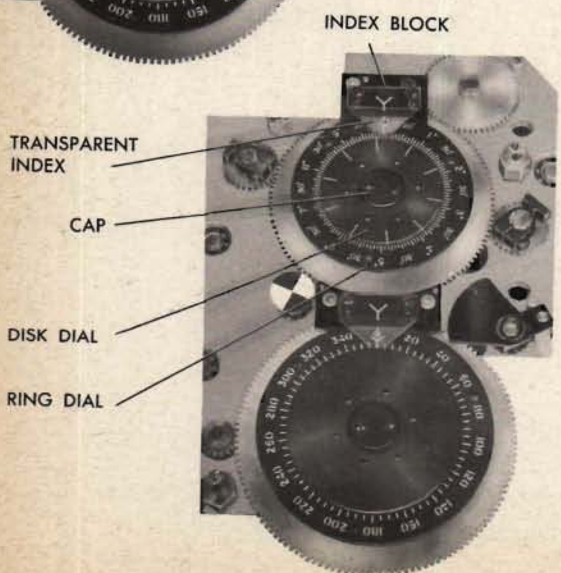
Repairing the large gear

If the large gear is bent, remove it from the assembly. Do not attempt to straighten it in the assembly, because a blow on the gear will make the balls pit the plate and the gear.

Burrs on the gear teeth can be removed by stoning. Clean and lubricate the gear before reassembly.







Reassembling the unit

This reassembly procedure is for the ball-retainer type.

1 Replace the ball retainer in the fine dial assembly. Be sure that all the balls are retained, yet free to rotate. Lubricate the retainer, the balls, and the bearing for the shaft.

2 Check the shaft for burrs. Polish it if necessary.

3 Replace the gear and the hub. Check the gear meshes. Lubricate the gear and the bearing.

4 Pin the hub to the shaft. Using a dial indicator with its point against the surfaces which support the disk dial, make sure that the hub runs true.

5 Replace the index block.

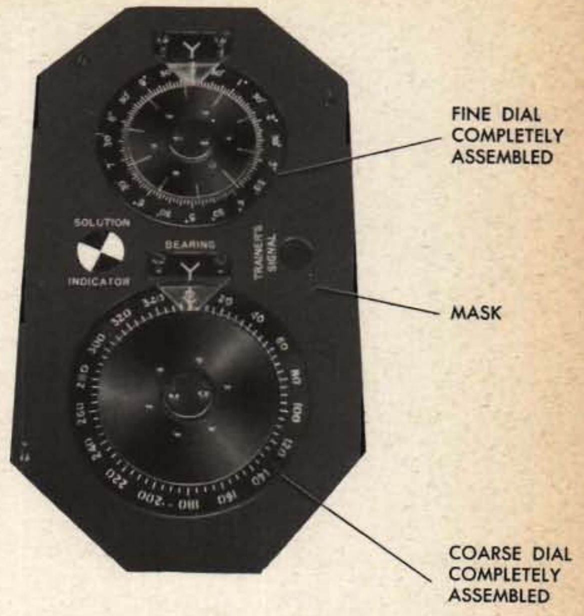
6 Mount the fine ring dial. Using a dial indicator with its point as near the top of the inner edge as possible, make sure that the ring dial runs true.

7 Replace the fine disk dial and secure it in place with the cap and screws.

8 Replace the transparent index.

9 Replace the mask.

10 Follow the same procedure in reassembling the coarse dial.



Bench checking the unit

1 Be sure that the dials do not rub.

Insert a piece of paper between the dial and the adjacent part and move the paper completely around the dial. Repeat this operation with the dial in at least four positions of its working range.

2 The unit should have been properly lubricated.

3 The dial assembly should move freely on the ball retainer.

4 The index line and the crowfoot on the index plate should be in line.

5 The gear meshes should be free and have a minimum of lost motion.

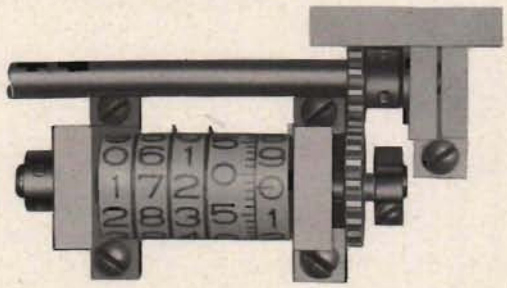
6 The dials should not be damaged or bent.

COUNTERS

LARGE COUNTER

A counter is usually mounted in a housing, but it may be mounted between hangers without a housing. A counter in a housing can be removed from the instrument by taking out the screws which hold the housing to the plate. A counter which has no housing can be removed by taking out the hanger screws.

Never try to repair a damaged counter if a replacement is available.



COUNTER MOUNTED
BETWEEN HANGERS

SMALL COUNTER

Typical symptoms

If a counter is not operating normally, check for one of the following typical symptoms:

JAMMING: The counter input shaft will not turn.

STICKING: The counter input shaft resists turning past a certain point or points.

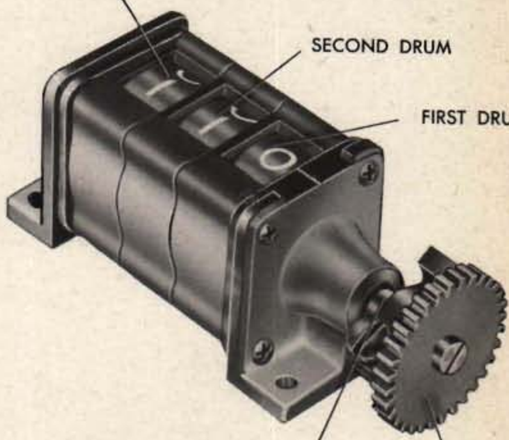
EXCESSIVE LOST MOTION: There is too much play between the input gear and the counter drums.

SLIPPING: A drum remains stationary when the counter input shaft is turned.

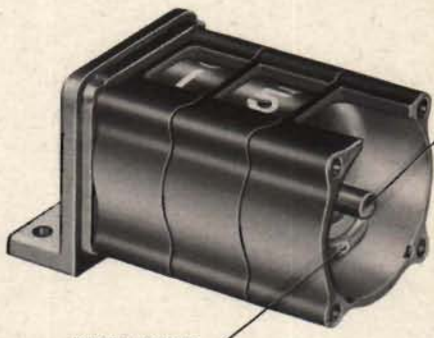
Locating the cause

Jamming or sticking

If a large counter jams or sticks, the trouble is probably caused by a bent or dirty input shaft, drum shaft, or intermittent gear shaft; dirty or damaged teeth on the drum gears or intermittent gears, or dirt or damage inside the housing.



Try to turn the input shaft. If the first drum jams or sticks, the input shaft may be bent or dirty, or the first drum may be sticking on the drum shaft or against the housing. If jamming or sticking occurs when the second or third drums should begin to turn, the drum shaft or intermittent gear shaft may be bent or damaged; or the intermittent gear teeth or the teeth on the inside of the drums may be dirty or damaged.

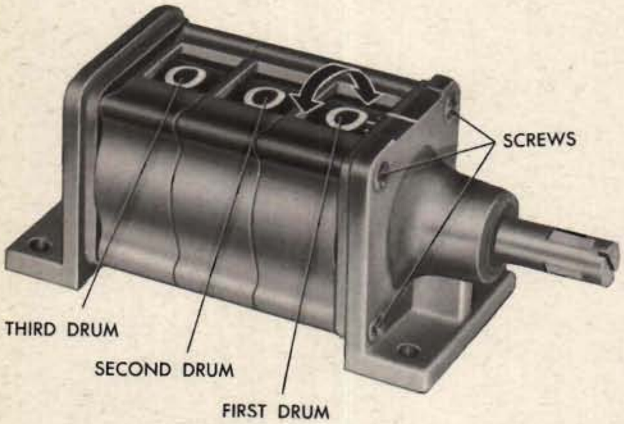


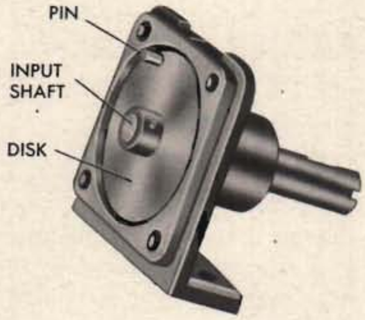
If the input gear wobbles when the input shaft is turned, the shaft is probably bent and should be removed for repair.

If the trouble seems to be in the second or third drums or the drum shaft, the unit must be completely disassembled to clean or repair the parts.

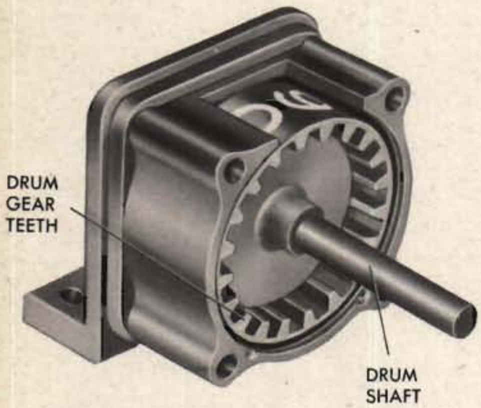
Excessive lost motion

If the first drum can be turned back and forth when the input shaft is held, the pin on the disk fastened to the input shaft may be loose or worn; the gear teeth in the first drum or the hole in the drum may be worn.

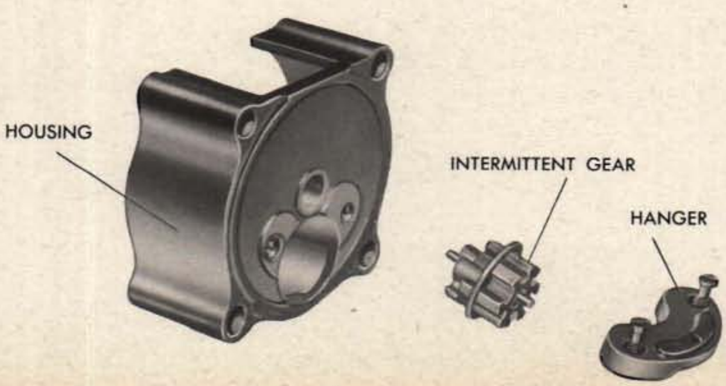


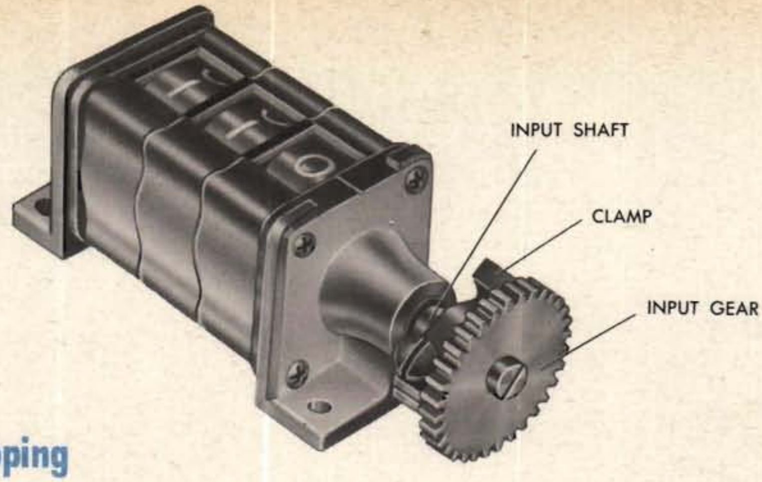


If the second or third drums can be turned back and forth when the input is held, the teeth on an intermittent gear or the teeth in the second or third drums may be worn.



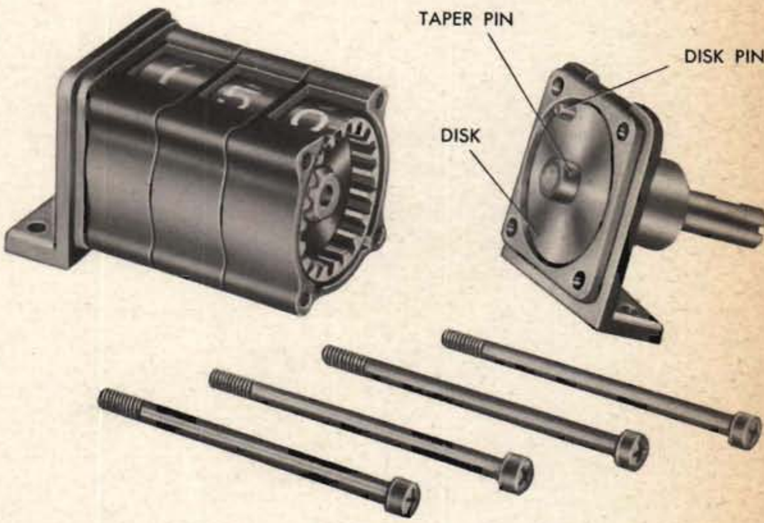
Only partial disassembly is required to repin the disk on the input shaft or to rivet a new pin to the disk. If the drum hole, the drum shaft, or any gear is worn, the unit must be completely disassembled for repair.

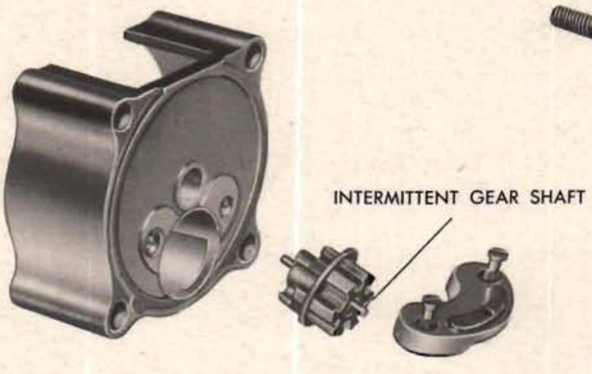




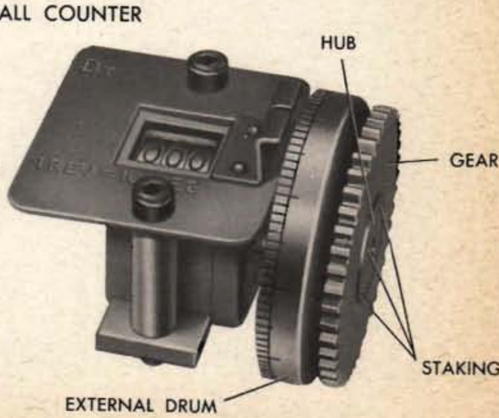
Slipping

If the counter slips when the input gear is turned, the gear may be slipping on the input shaft, a taper pin may be missing, or an intermittent gear shaft may be sheared or missing.





SMALL COUNTER



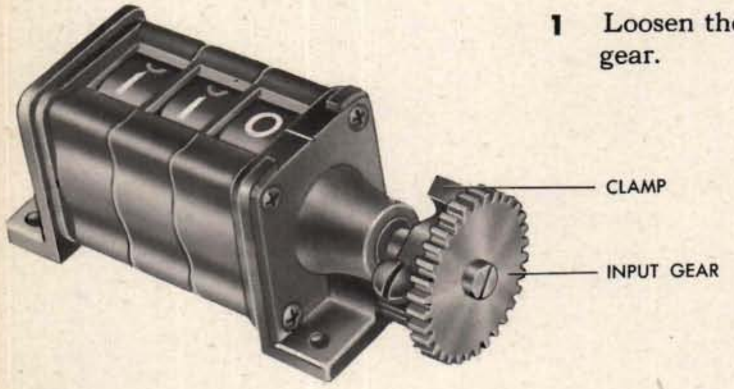
The gear on the external drum of a small counter may slip on the hub if the staking is broken.

If the input gear slips on the shaft, tighten the clamp on the split hub so that it will hold the gear firmly on the shaft. If the cause of slipping is located inside the housing, the unit must be disassembled for repair.

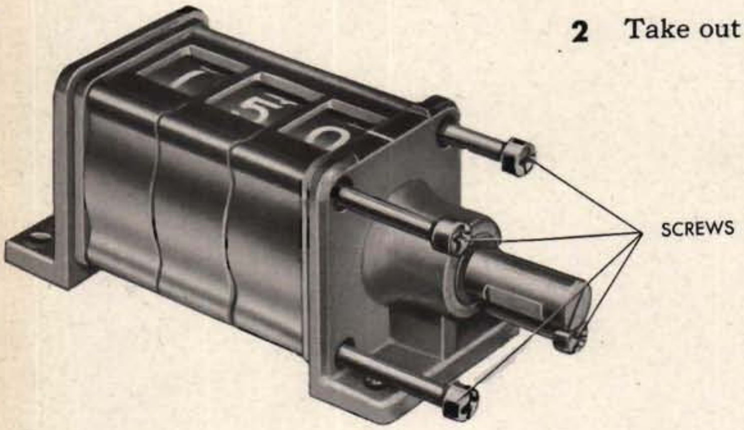
Disassembling the unit

This is the disassembly procedure for a large counter:

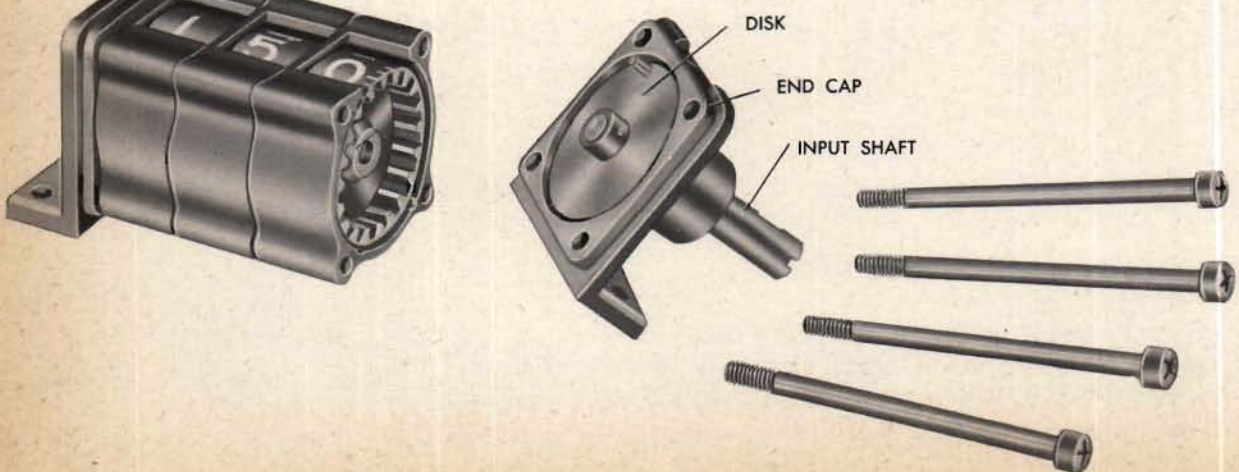
1 Loosen the clamp and remove the input gear.



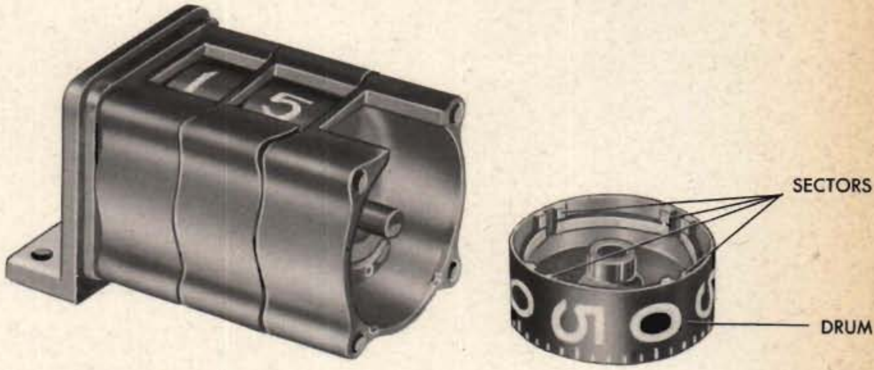
2 Take out the four long screws.



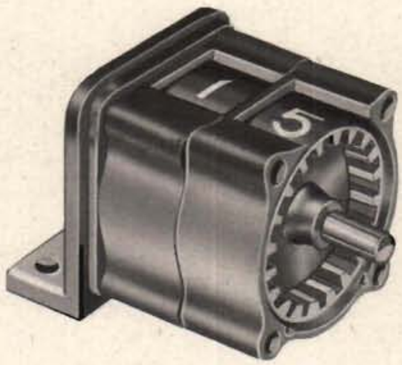
3 Remove the end cap containing the disk and input shaft.

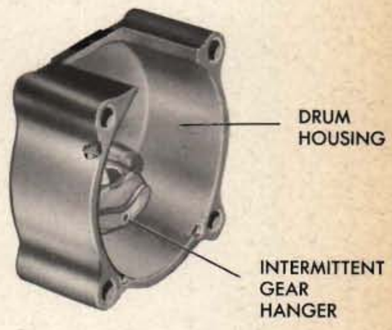


4 Remove the drum which has four sectors.

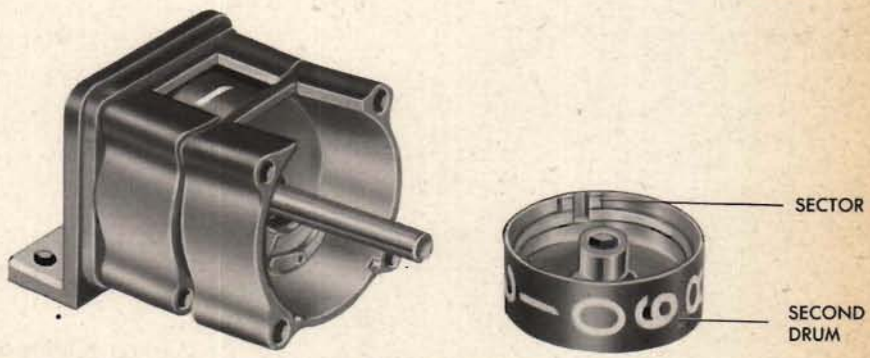


5 Remove the first housing containing an intermittent gear.



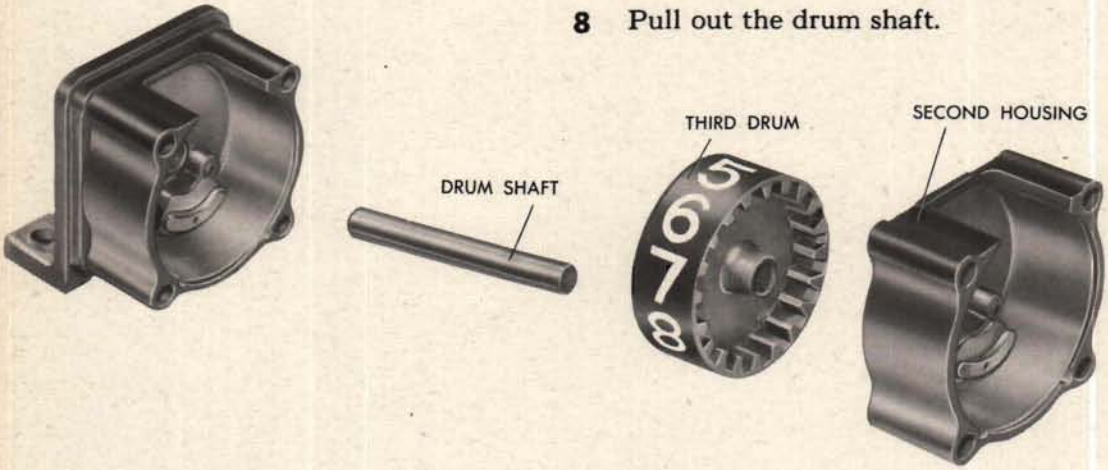


6 Remove the drum which has one sector (the second drum).

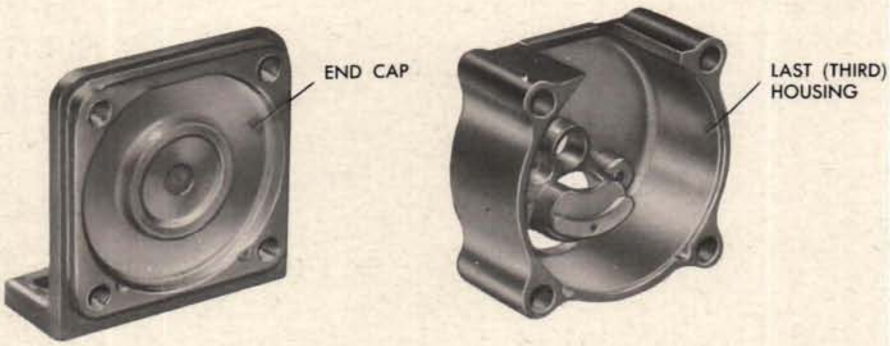


7 Remove the second housing and the third drum.

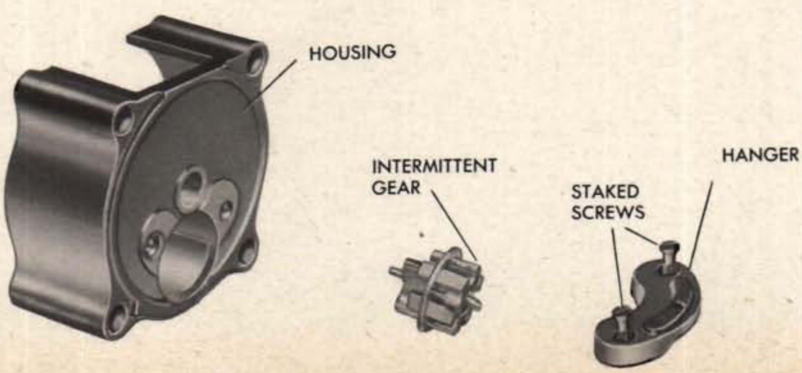
8 Pull out the drum shaft.



9 Separate the last (third) housing from the end cap.



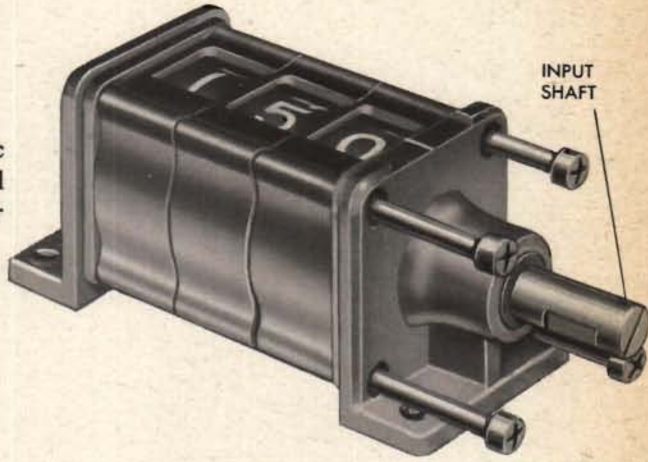
10 If necessary, the intermittent gears can be taken from their housings by removing the hangers which are held in place with staked screws.



Repairing the parts

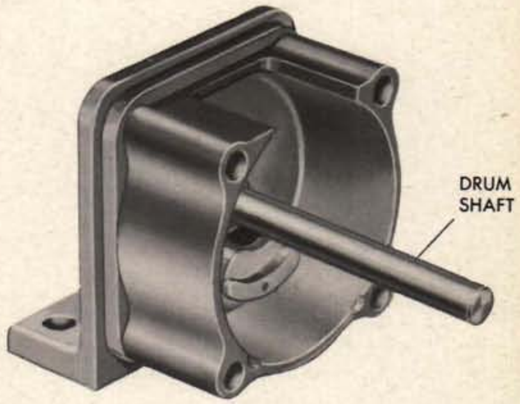
Repairing an input shaft

To straighten a bent input shaft, refer to *Basic Repair Operations,* pages 68-71. Only partial disassembly of the unit is necessary to repair or replace an input shaft.

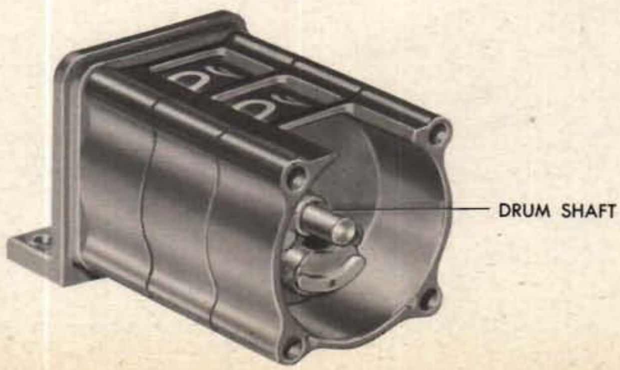


Repairing a drum shaft

To repair a drum shaft, the unit must be completely disassembled. A slightly bent shaft can be straightened. Polish a shaft that is too tight or burred. Keep trying it in the drums until it fits smoothly but without excessive looseness.

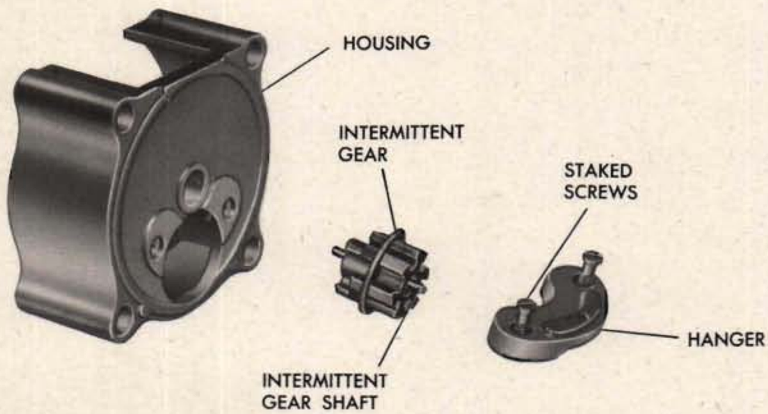


If a drum shaft must be replaced, make sure that the new one is the proper length. Compare the length of the replacement shaft with the old shaft. If the replacement shaft is too long, shorten it to agree with the old shaft. Try it in place. Remove it for cleaning and lubricating before final assembly.



Repairing an intermittent gear shaft

If possible, replace the entire drum housing assembly. If a replacement is not available, however, the damaged shaft can be removed for repair or replacement. Smooth a slightly burred shaft with a fine oilstone, but replace a badly damaged one. Clean the shaft and hangers and lubricate the shaft before reassembly. Be sure to stake the gear tightly to the shaft at both ends.

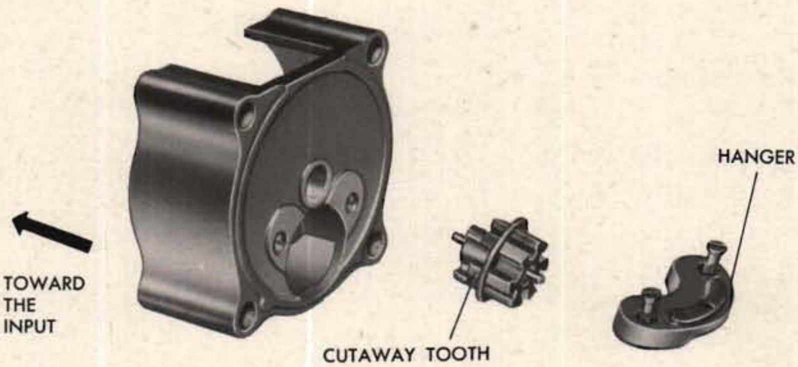


Repairing a drum

If possible, replace a damaged drum. If the surface of the drum is damaged and no replacement is available, the surface can be reworked. Support the drum from the underside while reworking the surface. Carefully polish the metal before repainting. Smooth any rough surfaces inside the housing with a fine jeweler's file and clean the housing thoroughly before mounting the drum in the housing.

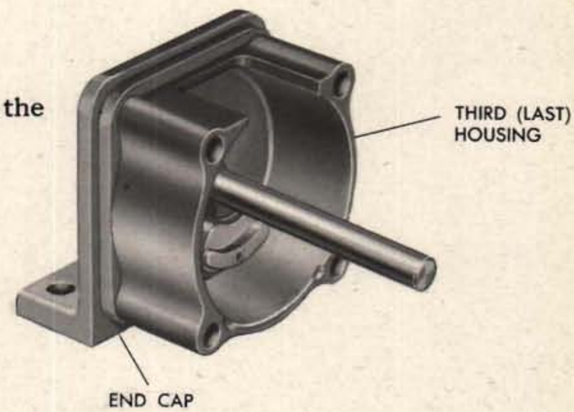
Reassembling the unit

1 Mount each intermittent gear in its housing so that the cutaway teeth will be toward the input end of the housing. Mount the hangers. Tighten and stake the hanger screws.

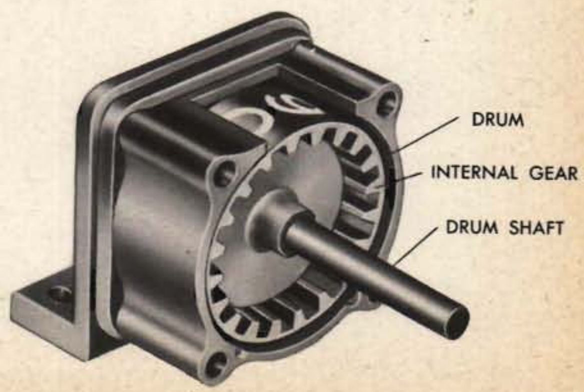


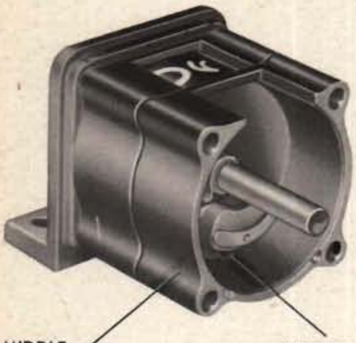
2 Replace the "third" (last) housing on the end cap.

3 Mount the drum shaft.



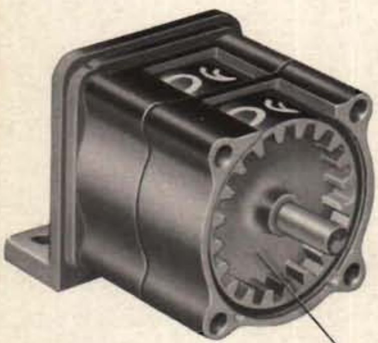
4 On the drum shaft, mount a drum which has one sector. The internal gear should be toward the input end of the counter.





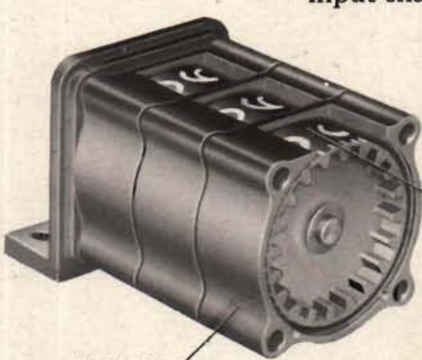
5 Hold the mounted drum with both the zero and the nine showing at the window. Position the intermittent gear with the full tooth down and replace the middle housing.

6 Replace the "second" drum, which also has only one sector, so that the zero and nine show at the window and the internal gear faces the input shaft.



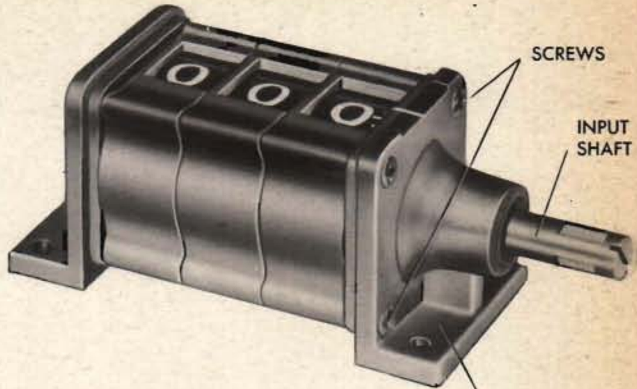
7 With a full tooth of the intermittent gear facing downward, replace the "first" housing.

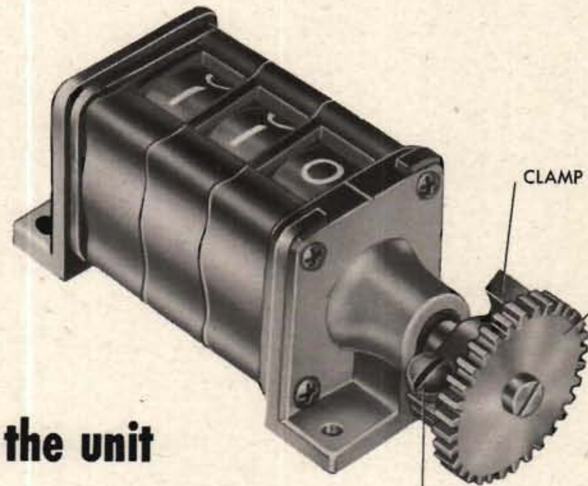
8 Replace the "first" drum, having the four sectors, so that a zero and a five line up with the zeros and nines on the other drums and the internal gear faces the input shaft.



9 Replace the end cap with the disk and input shaft and tighten the four screws.

10 Mount the clamp and input gear and tighten the clamp.





Bench checking the unit

1 Be sure that the counter turns freely.

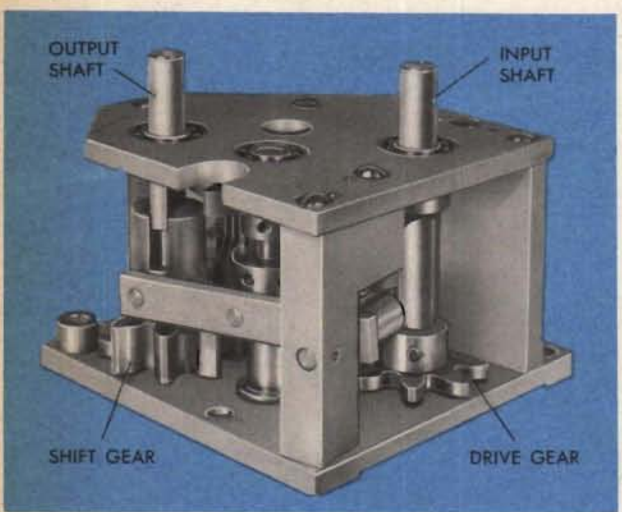
2 Slowly turn the input shaft to make sure that the drums operate correctly at all transfer points.

When the unit drum moves ten graduations, the second drum should shift one number. When the second drum has made one complete revolution, the third drum should shift one number.

3 Check the counter for excessive lost motion.

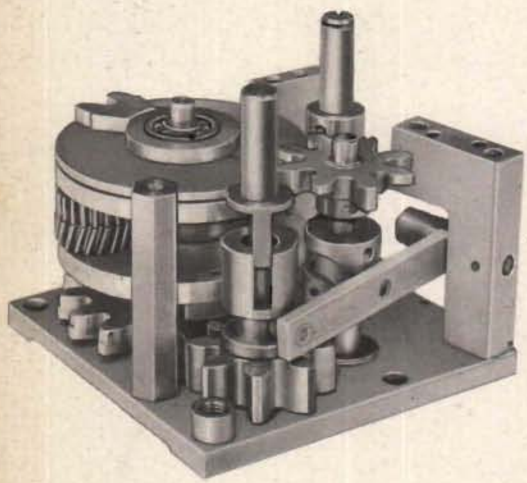
4 The input shaft must have minimum end play.

THE INTERMITTENT DRIVE



An intermittent drive is always mounted between its own two plates. It is used as a single unit on a shaft line connecting two mechanisms which have different limits of operation. Each intermittent drive has an input shaft and drive gear near one plate corner, and an output shaft and shift gear at the opposite corner. When the shift gear is cut out of mesh, the output shaft is locked even though the input shaft continues to drive.

Before the unit can be removed, some adjacent gearing and mechanisms may have to be taken out. Then the entire unit can be removed for repair or replacement. If the unit must be removed, consult the instrument OP for instructions.



TOP PLATE REMOVED

Typical symptoms

If test analysis and unit check tests have indicated that an intermittent drive is not operating normally, look for the following typical symptoms:

JAMMING: The input shaft cannot be turned by hand.

STICKING: The input shaft resists turning or is sluggish.

EXCESSIVE LOST MOTION: There is too great a lag between the turning of the input gear and the turning of the output gear.

SLIPPING: The output shaft does not turn, although the shift gear is cut in and the drive gear is turning.

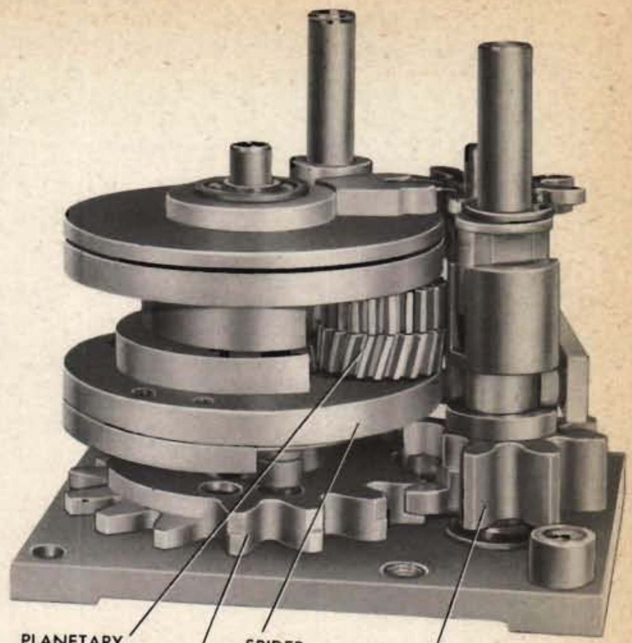
Locating the cause

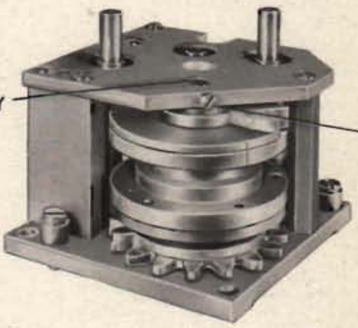
Jamming or sticking

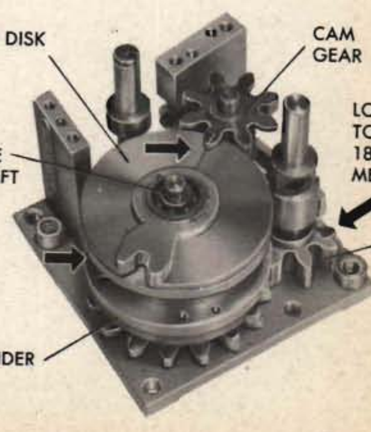
The shift gear may jam or stick against the spider at its cut-in or cut-out point because the unit is out of adjustment, or because of a bent shaft, an excessively bent lever arm, or a dirty, damaged, or loose cam or cam lever follower. If the input shaft cannot be turned by hand, the gears or the output shaft slot may be dirty or damaged.

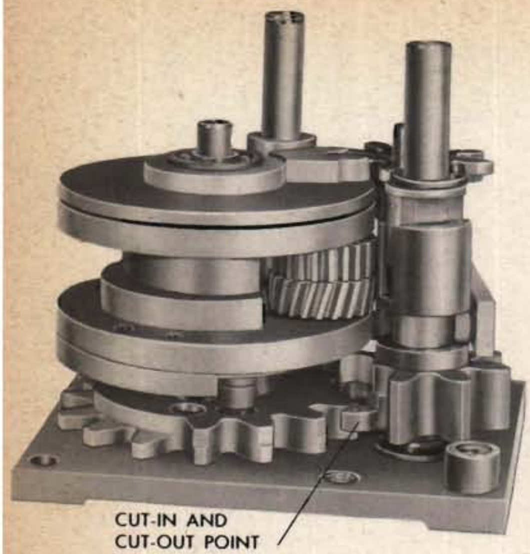
If the shift gear jams or sticks at the points where it cuts in or out of mesh with the spider gear, check to see that the screw dowel holes are of the proper diameter and in line with each other, and that the screw dowel is not bent, sheared, or missing. If the hole is distorted or the screw dowel is sheared or missing, the unit is probably out of adjustment.

To check for proper adjustment, turn the input shaft until the marked tooth on the camshaft gear lines up directly with the mark on the locking disk. At the same time, the mark on the side of the locking disk should line up with the mark on the side of the spider when the locking tooth on the shift gear is 180° out of mesh, and the planetary gears are next to the output shaft. Now it should be possible to insert a screw dowel through the edge of the top plate and into the stationary shaft.





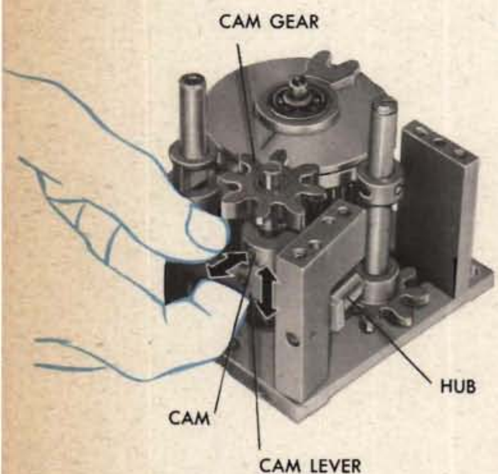


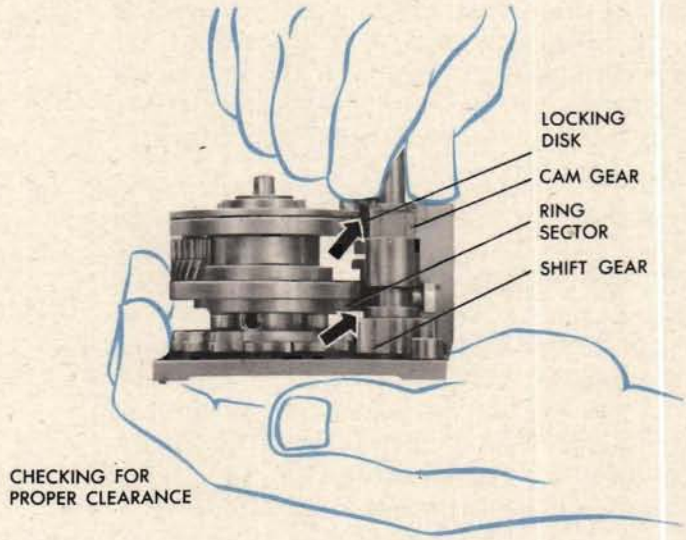


If the input gear jams or sticks at the cut-in or cut-out point when the unit is correctly adjusted, one or more of the shafts may be bent. To locate a bent shaft, carefully examine all gears on the input, output, stationary, planetary, and cam shafts for wobble. To repair or replace a bent shaft, the unit must be at least partially disassembled.

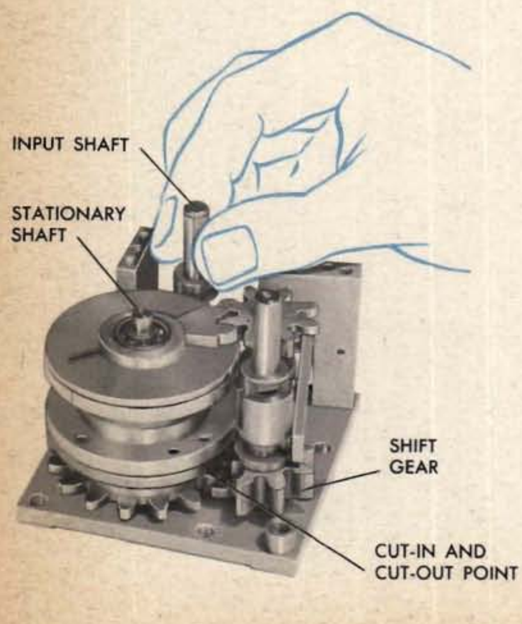
If the unit is correctly adjusted, but still jams or sticks at the cut-in and cut-out points, the source of the trouble may be in the cam, the cam lever, or the cam lever hub. Examine the cam lever to see whether it is bent or loose, and the cam, cam lever, cam follower, and lever hub for looseness, wear, and dirt.

Only partial disassembly of the unit is necessary in order to repair or replace these parts.





CHECKING FOR
PROPER CLEARANCE



If the input gear jams or sticks in any position when the unit is correctly adjusted, check all bearings and gear teeth for dirt, and the input and stationary shafts for run-out. Check also for adequate clearance between the shift gear and the ring sector and between the cam gear and the locking disk.

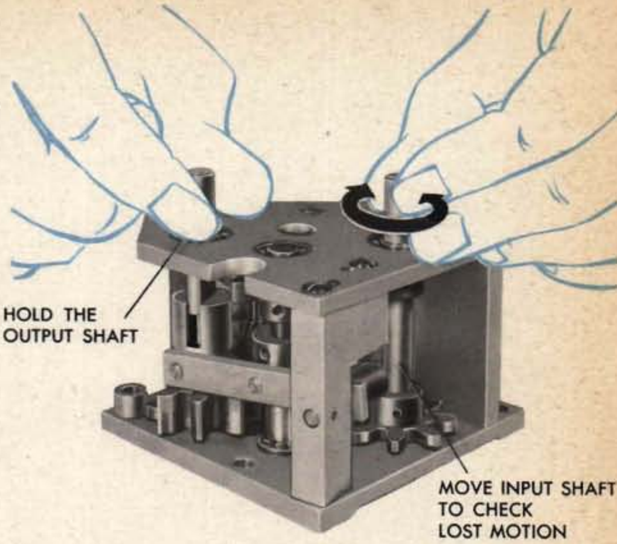
The sun gears can be inspected only when the unit is disassembled. Remove any dirt or embedded particles from these gears and lubricate them. Turn the input gear to see whether the shift gear will now cut in or out without jamming.

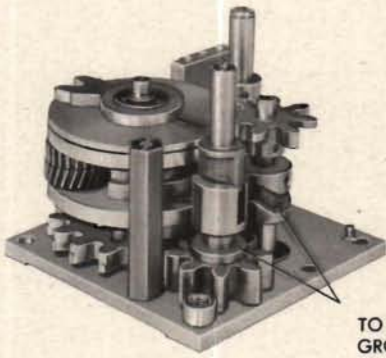
Excessive lost motion

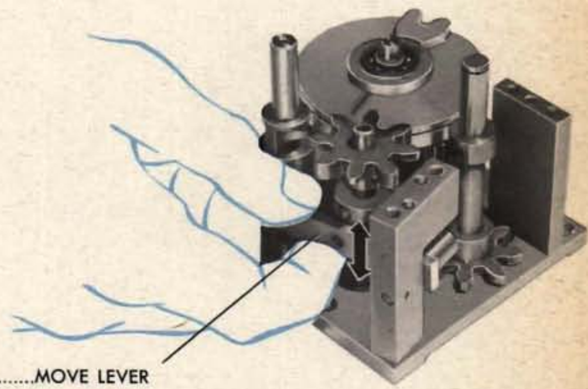
Excessive lost motion between the input and the output shafts may be caused by worn or damaged gear teeth.

Carefully examine each pair of meshing gears in the unit for dirt or embedded particles and for worn or damaged gear teeth.

Check the end play in the cam shaft.

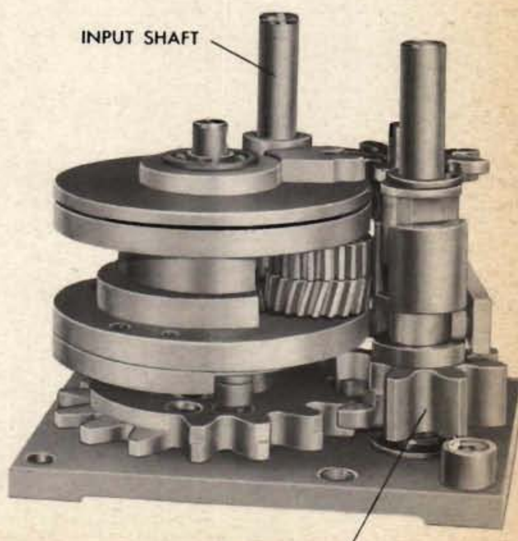






Slipping

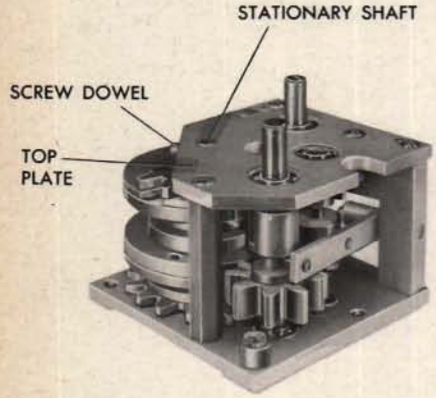
Slipping of the shift gear when it is cut in and the drive gear on the input shaft is turning is probably caused by a missing or sheared pin. Inspect the cam and all gear hubs and collars for a missing or sheared pin.

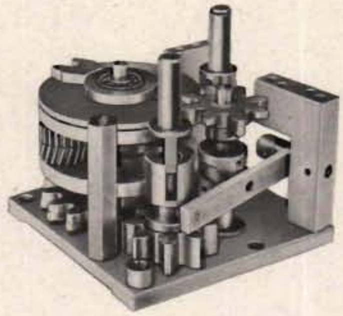


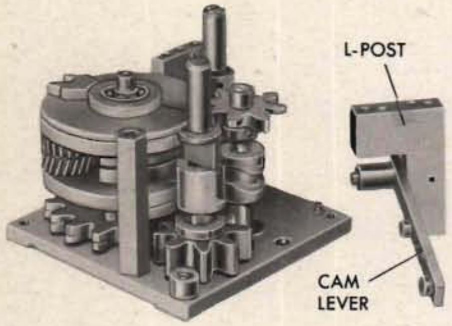
Disassembling the unit

1 Remove the screw dowel which goes through the top plate and into the stationary shaft.

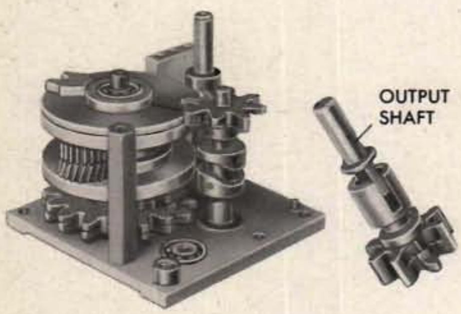
2 Unscrew the five screws holding the top plate and remove the plate.



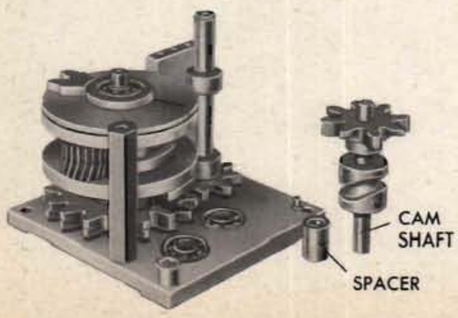




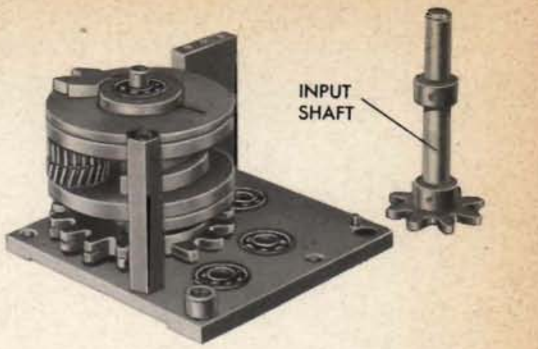
3 Remove the L-shaped post and the cam lever fastened to it by taking out the screw under the lower plate.



4 Lift off the output shaft.

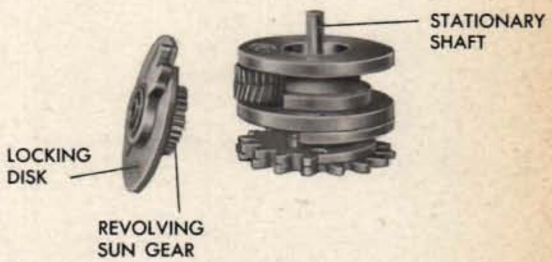


5 Remove the cam shaft and spacer.

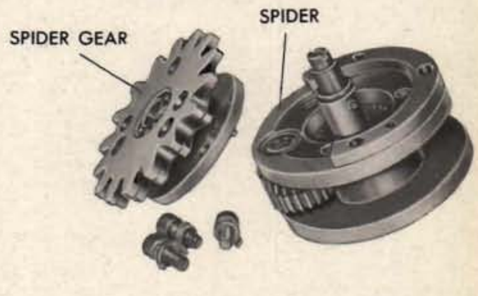


6 Lift off the input shaft.

7 Remove the planetary assembly consisting of the spider gear, the spider, and the locking disk. To do this, tap gently on a rod held against the slotted lower end of the shaft, from below the lower plate.

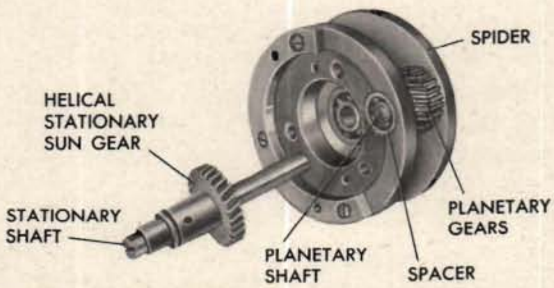


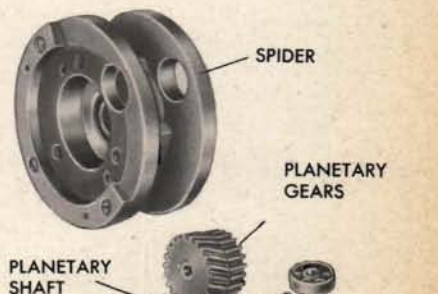
8 Gently pry up the locking disk and pull it off the stationary shaft. The revolving sun gear is attached to the disk and will come off with it.



9 Unscrew the three screws which hold the gear on the spider, and remove the spider gear.

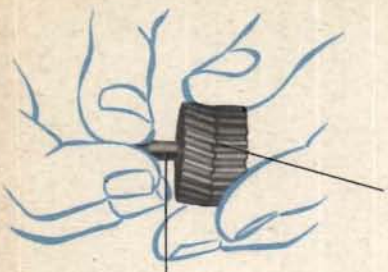
10 Lift the stationary shaft out of the spider and remove the planetary gears by tapping their shaft out of the spider.





Repairing the parts

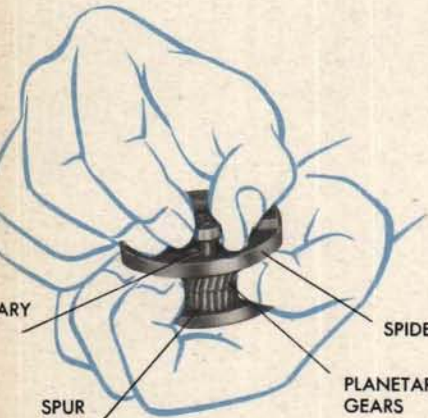
Replacing planetary gears



Be sure that both new gears are clean and undamaged before riveting them together. Mount the two gears on a temporary shaft, align the teeth, and then rivet the gears together so that there is no space between them. For a detailed explanation of riveting, see page 76.

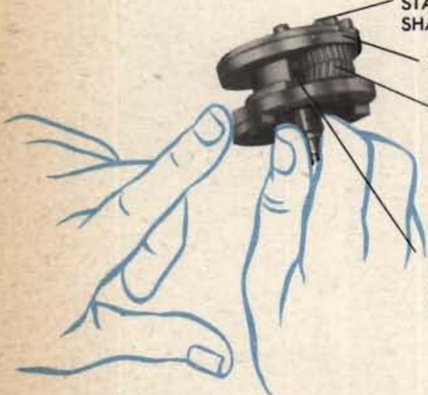
File the rivets flush on both sides.

Check the shaft for straightness.

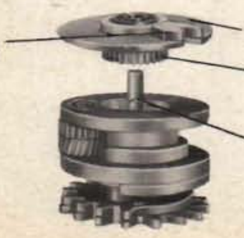


Ream the hole in the gears to a hand push-fit on the planetary shaft, and mount the shaft and gears in the spider with the spur gear on top. Invert the spider and install the shaft through the bottom plate. Check the gear assembly for excessive end play and wobble.

Replacing sun gears



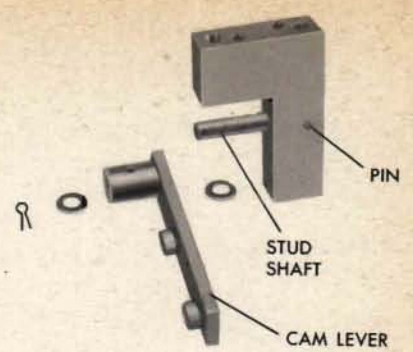
Check the stationary shaft for straightness. Be sure that the new stationary sun gear is clean and undamaged. Mount the shaft in the spider and turn the spider to check the mesh between the stationary sun gear and its planetary gear. Check lost motion between this pair of gears.



Be sure that the new sun gear which turns is clean and undamaged. Remove any dirt or foreign matter, seat the gear in the locking disk, and rivet it. Check the two teeth of the sector gear on top of the locking disk for wear.

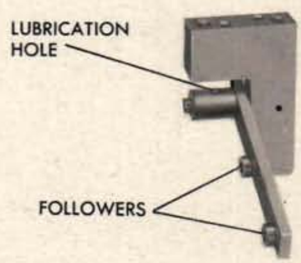
Mount the gear and locking disk on the stationary shaft. Check to see that the gears are free to turn with a minimum of lost motion. Lubricate the gears.

Replacing a cam stud shaft and hub



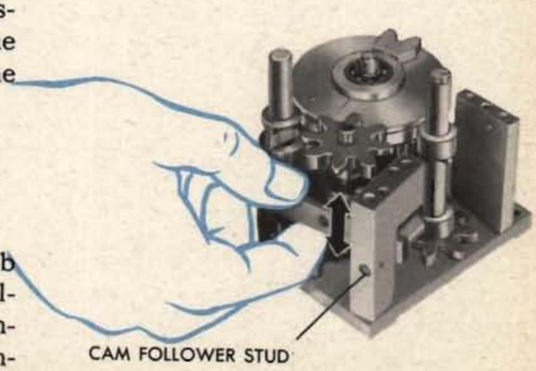
Remove the cotter pin from the stud shaft and slide off the spacers and cam lever. Repin the stud shaft to the L-post if it is loose.

Lubricate the shaft and fit the new hub to it. Test the hub for wobble and smoothness of operation on the stud shaft.



Remove the hub. Seat and rivet the new hub in the cam lever so that the hole is on top of the hub for convenient lubrication of the shaft. Lubricate the stud shaft and mount the cam lever on it with a spacer between the L-post and the lever. Replace the outer spacer and the cotter pin and check for smoothness of operation.

Fitting a new follower



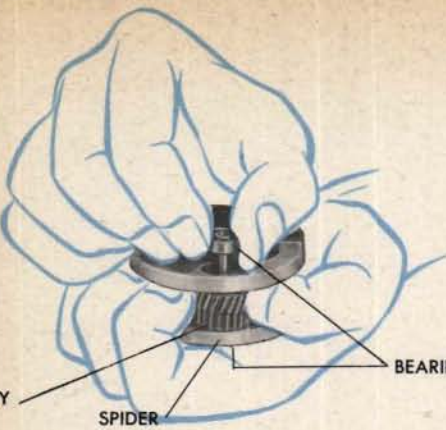
Lubricate the cam follower stud and, if necessary, ream the follower to fit freely on the stud with a minimum of lost motion. If the follower is too loose, install a larger stud.

Try the follower in the cam or shift-gear hub groove and check for lost motion. If a cam follower stud is loose, remove it and rivet another securely in its place. For riveting instructions, see page 76.

Reassembling the unit

Wash and dry all the parts before starting to reassemble the unit, and lubricate each part before replacing it. Use grease on the gears, grooves, studs, shafts, and the vertical slot in the output shaft collar. Put a drop of light machine oil in each bearing.

In reassembling the parts, be sure that all parts are in the same relative positions as before disassembly.



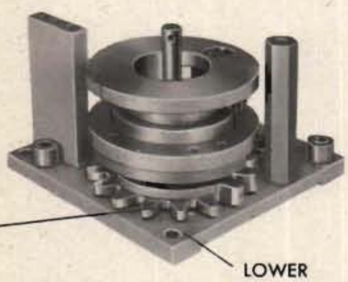
1 Replace the planetary gears, the bearings, and the spacer in the spider.

2 Mount the assembly consisting of the stationary sun gear and stationary shaft in the spider.

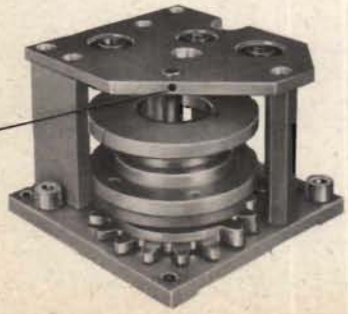
3 Push the spider gear assembly into position on the spider and tighten the three screws.

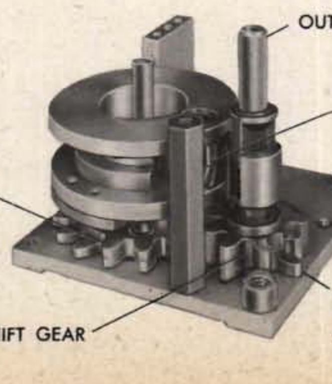
4 Place this part of the planetary assembly on the lower plate.

5 Replace the top plate temporarily. Line up the dowel hole in the stationary shaft and the top plate. This can be done by turning the slotted end of the stationary shaft. Remove the top plate, being very careful not to disturb the shaft position.



6 Replace the output shaft and mesh the shift gear with the spider gear so that the cut-away tooth is 180° out of mesh and the planetary gears in the spider are toward the shift gear. Hold the gears in this position.





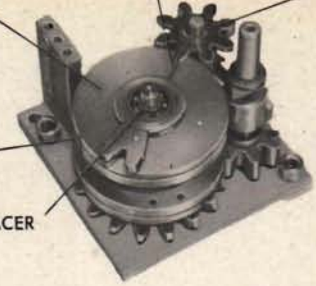
7 Replace the locking disk and the cam shaft at the same time. Be sure to line up the marks on the gear tooth and the disk, and on the spider and the side of the disk. Replace the spacer on the stationary shaft.

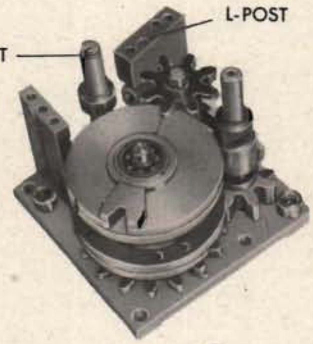
8 Replace the input shaft.

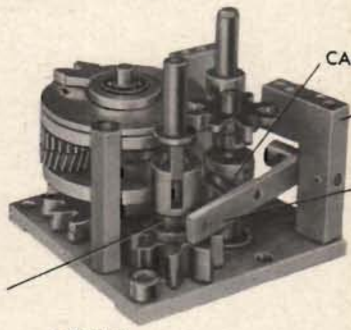
9 Replace the L-shaped post and carefully fit the followers on the cam lever into the grooves in the cam and in the shift gear hub.

10 With all the scribe marks still lined up, carefully lower the top plate into position, replace the screw dowel in the stationary shaft, and fasten the plate with the five screws.

11 Turn the input shaft to see whether the shift gear will cut in and out smoothly.







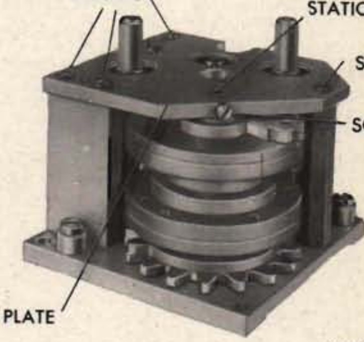
Bench checking the unit

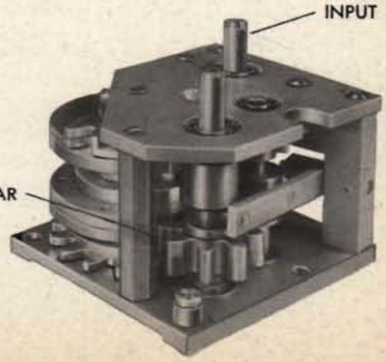
1 Check the assembly of the unit against the assembly drawings.

2 The mark on the side of the locking disk should line up with the mark on the spider at the same time that the mark on the cam-shaft gear lines up with the mark on top of the locking disk.

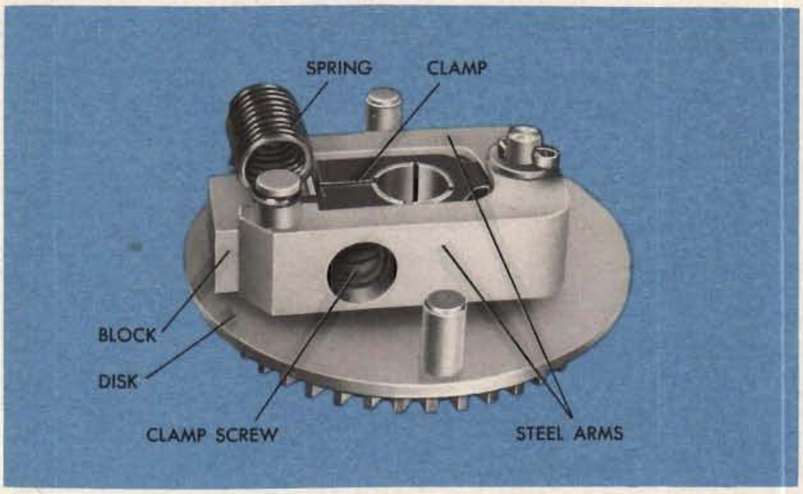
3 Shaft end play and lost motion between gears should not exceed allowable maximums specified on the assembly drawing.

4 Turn the input gear to see whether the shift gear cuts in and out smoothly. When the unit is correctly aligned, the input shaft drives the output shaft 29 turns. Then the output shaft remains stationary for 87 additional turns of the input shaft.





THE SHOCK ABSORBER



A shock absorber is clamped to the output shaft of an intermittent drive to prevent damage to gears when the output line suddenly starts turning. The clamp makes contact with two steel arms which are held by a spring against the sides of a block riveted to the disk. When the shaft suddenly starts turning, the clamp spreads the arms against the spring so that the first shock is absorbed and gradual acceleration of the gear is permitted.

A shock absorber can be removed from the shaft after the clamp screw has been loosened.

Typical symptoms

If a test analysis and a unit check test indicate that a shock absorber is faulty, look for one or more of the following symptoms:

JAMMING: An arm does not open or return to its normal position against the block after opening.

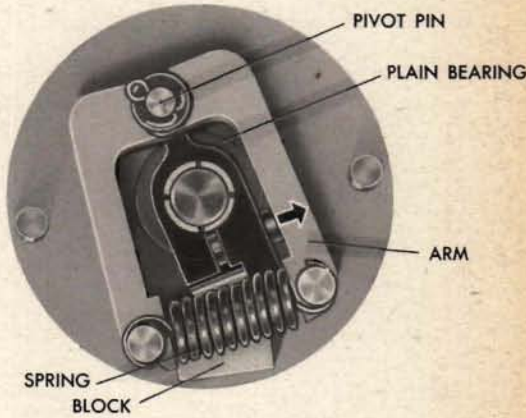
STICKING: An arm is sluggish in returning to its normal position against the block.

EXCESSIVE LOST MOTION: There is too much clearance between the block and one of the arms.

SLIPPING: The motion of the shaft is not carried by the unit.

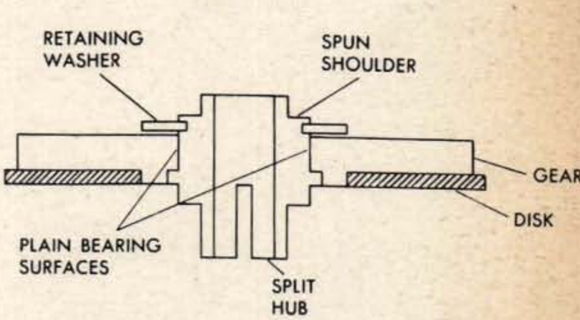
Locating the cause and repairing the parts

A SHOCK ABSORBER MAY JAM OR STICK because of a dirty or damaged plain bearing or pivot pin. Also, an arm may return to its normal position sluggishly because of a stretched or weakened spring which does not pull the arm back to the block.



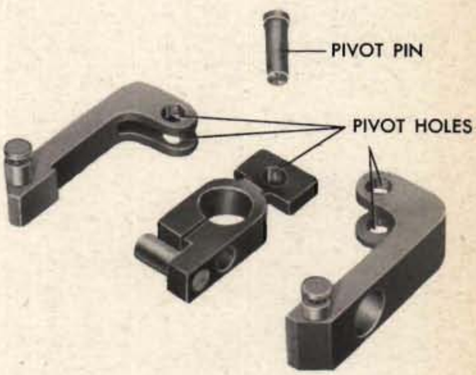
A shock absorber may appear to jam or stick because of an overloaded shaft line.

Replace a weak spring. To check for an overloaded shaft line consult the instrument OP.

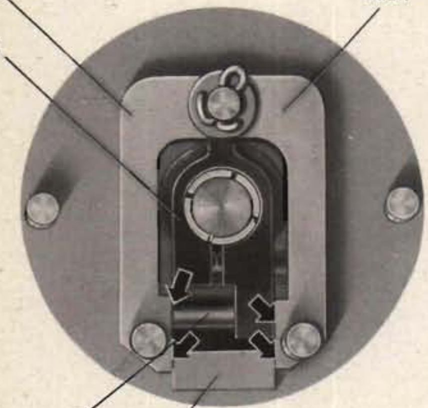


A plain bearing that jams or sticks must be removed from the unit and polished. To do this, disassemble the arms from the unit, mount the split hub end in a lathe and carefully turn off the spun shoulder which overlaps the retaining washer. Caution: removing too much of the shoulder may make the hub useless.

Drive the hub out of the gear. Polish, clean, and lubricate the bearing surfaces of the hub and the gear. Remount the hub in the gear and replace the retaining washer. Hold the assembly so that the split hub is protected and peen the shoulder over the washer. From time to time during the riveting operation, rotate the hub to be sure that it turns easily.



To smooth the pivot pin or the pivot holes in the arms, or to install a thinner spacer in the pivot-pin assembly, the unit should be disassembled. Polish the pivot pin, the holes in the arms, or the flat pivoting surfaces on the arms to remove any rust spots or roughness.



A SHOCK ABSORBER MAY HAVE EXCESSIVE LOST MOTION because the arms do not bear simultaneously against the block, the clamp post, and the clamp.

To correct excessive lost motion, the unit should be disassembled. A clamp post which is too long can be filed and polished to size. A block that is too small should be replaced. For instructions on riveting the block to the disk, see page 76.

A SHOCK ABSORBER MAY SLIP because the dowel pins holding the disk to the outer ring of the sleeve bearing are sheared, the clamp is loose or damaged or the shaft hole in the hub is too large. The unit must be disassembled to replace an oversize hub or a sheared pin. For instructions on replacing a pin, see page 74.

CLAMP ASSEMBLY

A loose clamp can be tightened in the instrument. A faulty clamp must be replaced.

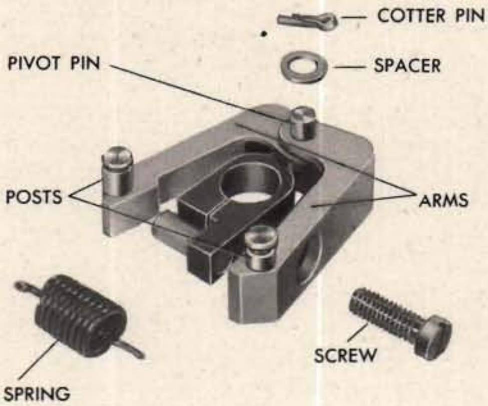
Disassembling the unit

1 Remove the clamp assembly from the disk and withdraw the screw.

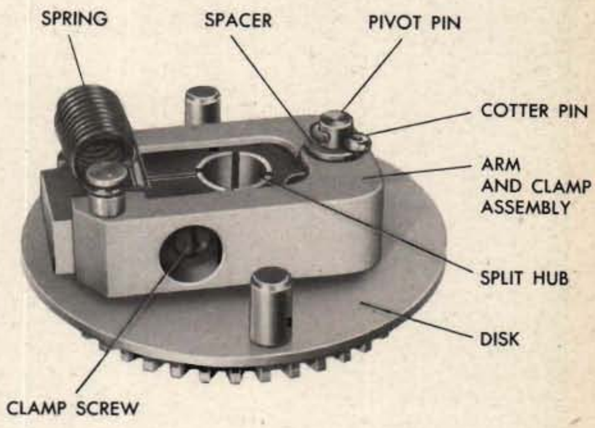
2 Remove the spring from the posts.

3 Remove the cotter pin and spacer from the pivot pin.

4 Remove the pivot pin from the arms and the clamp and separate the parts.



CLAMP ASSEMBLY



Reassembling the unit

1 Replace the arms and clamp on the pivot pin. Make sure that the clearance hole in the clamp faces the hole in the arm.

2 Replace the spacer. Use a new cotter pin if one is available.

3 Replace the spring.

4 Replace the arm and clamp assembly on the split hub.

5 Insert the clamp screw.

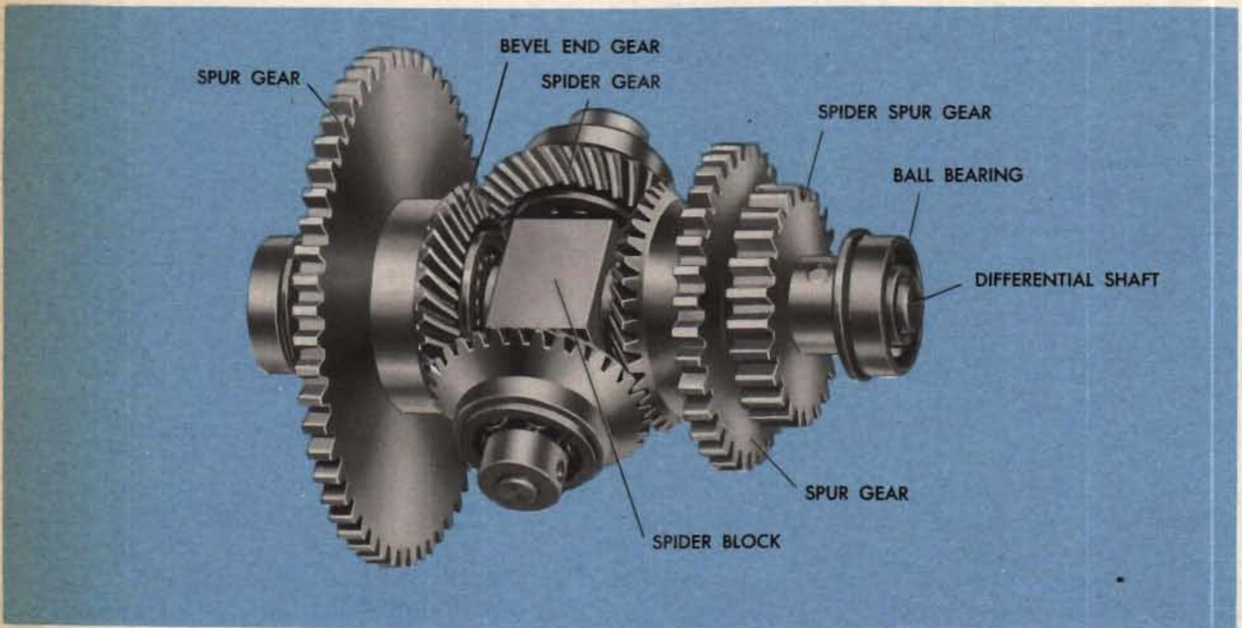
Bench checking the unit

1 Check the unit against the assembly drawing.

2 All moving parts should be well lubricated. Oiling the clamp screw will make later adjustments easier.

3 There should not be any lost motion between the arms and the block.

THE BEVEL GEAR DIFFERENTIAL



As a general rule, a differential suspected of causing faulty operation should not be removed from the instrument unless the particular cause of the trouble has been found in it and the repair cannot be made in place.

Nearly every differential shown on the instrument gearing and schematic diagrams bears a number which is also stamped on the spider block of the corresponding differential in the instrument.

Typical symptoms

Test analysis and unit check tests may have indicated that a certain differential is not operating properly. Check the differential for the following typical symptoms:

JAMMING: Gears ordinarily free to turn cannot be turned; or turning one gear turns them all.

STICKING: A definite tight spot, or bind, is felt in one or more of the gears.

EXCESSIVE LOST MOTION: The differential turns freely, but when the input gears are held, more than normal lost motion is felt in the output gear.

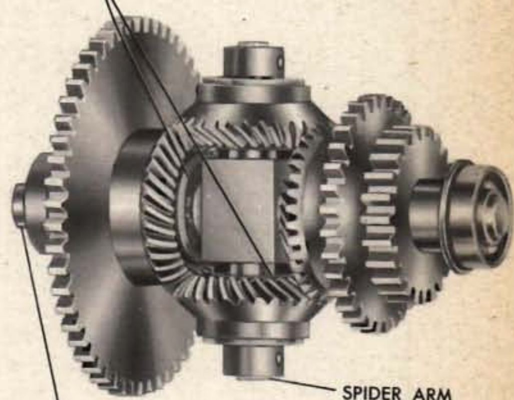
SLIPPING: Turning either input gear does not turn the output gear.

Locating the cause

Jamming or sticking

Differential jamming or sticking may be caused by a bent differential shaft or spider arm, damaged gear teeth, defective bearings, or dirt or chips between gear teeth. Try to determine by inspection whether one of these defects is causing the trouble.

It may be possible to remove foreign matter from the gear teeth while the differential is still in place. Making any of the other repairs, however, requires removal of the differential from the instrument. Damaged gears or defective bearings must be replaced. A bent shaft or spider arm may be removed and straightened if it is not bent too much.



Excessive lost motion

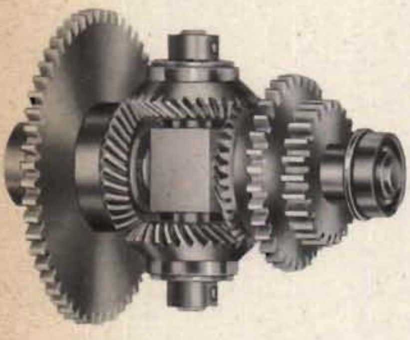
Excessive lost motion may be caused by worn bevel-gear teeth or incorrect reassembly of spacers. To reduce lost motion, the differential must be removed and disassembled.

Slipping

A differential may slip if the bevel-gear teeth are stripped, a spur gear slips on its hub, or a taper pin is sheared or missing from the spider block. Repair will require removal of the differential.

Removing a differential

A differential may be a part of a unit or a shaft line. Frequently units can be removed from the instrument and disassembled on the bench in less time than it takes to disassemble them in place. Study the location of the differential in order to decide whether removal of the entire unit or of the differential alone will take less time and work. Remember that removing the differential may disturb the relationship of at least three shaft lines, but removing a complete unit may disturb many more. The instrument schematic and gearing diagrams must be consulted to determine how many lines will be disturbed. Consult the instrument OP to see whether there are special instructions for removing any particular differential.



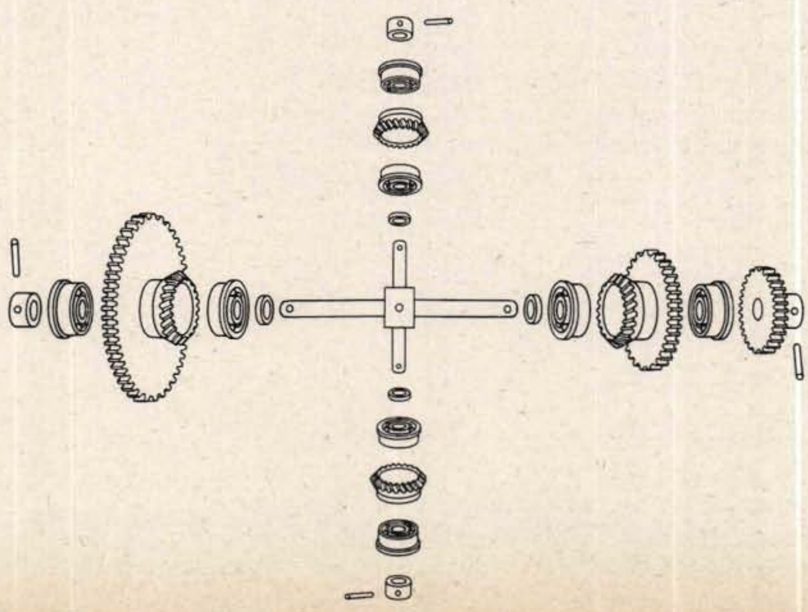
A COMPLETE DIFFERENTIAL

It is important to remove or reinstall a differential as a unit wherever possible, in order to avoid disturbing the bevel-gear meshes. Often frictions or other mechanisms are mounted on a differential shaft, but the actual differential includes only the parts illustrated here.

Differentials are made in three common sizes, according to the shaft diameter: 5/16, 1/4, and 3/16 inch. The spider gears on the two larger differentials are held by taper-pinned collars. On the 3/16-inch differential, each spider gear is held by a spacer and a snap ring which fits into a groove in the shaft.

To disassemble a 5/16 or 1/4-inch differential, drive out the taper pins at the ends of the shaft and the spider arms. On a 3/16-inch differential, remove the snap rings. Remove all the parts from the shaft and the arms, one at a time, and place them in rows on the bench in their proper order for reassembly. *Be sure to keep each spacer and taper pin with its part.*

A DIFFERENTIAL DISASSEMBLED

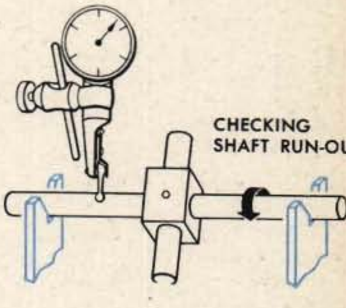


Repairing the parts

Straightening a shaft or spider arm

Remove all the parts from the shaft except the spider. To check the shaft for run-out, mount it on V-rests on a surface plate and use a surface gage and a dial indicator. The maximum allowable run-out is 0.0005 inch total indicator reading. Straighten the shaft as described in the chapter on *Basic Repair Operations,* pages 68 and 69.

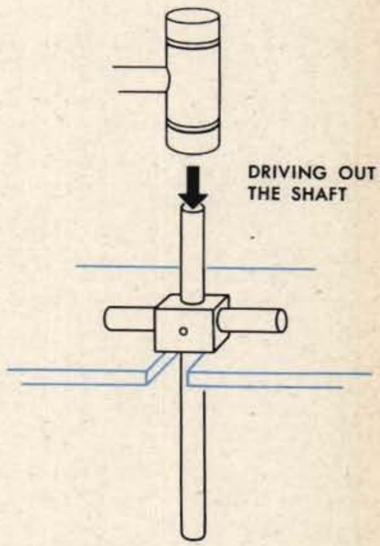
The run-out check for the spider arm is the same as for the shaft, and the same method of straightening is used. A spider arm should be replaced if it is bent more than 0.002 inch.



CHECKING SHAFT RUN-OUT

Installing a new shaft

Tap out the spider-block taper pin and gently drive out the shaft with a plastic hammer. Insert the new shaft in the spider, reaming the hole only if necessary. Install an oversized taper pin. If necessary, polish the shaft to make it fit the end-gear bearings.

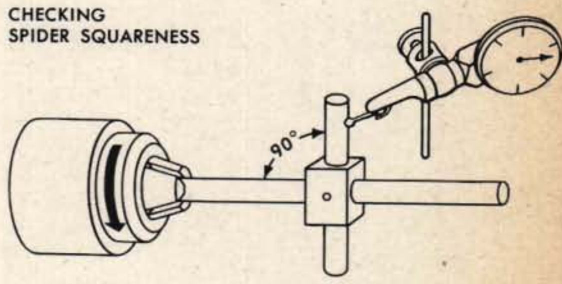


DRIVING OUT THE SHAFT

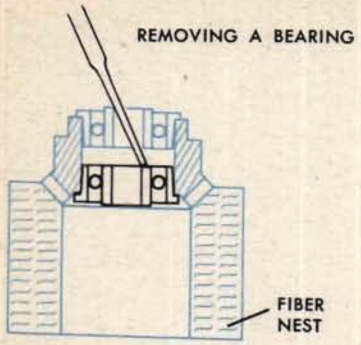
Checking the squareness of the shaft and spider

After it has been determined that the shaft and spider arms are straight, the squareness of the spider arms must be checked with a dial indicator. To do this, support the shaft in such a way that it can be rotated without either lengthwise motion or run-out. Position the indicator against the side of one spider arm. Turn the shaft and note the two readings as the spider arms pass the indicator. The difference between the readings should not exceed 0.0005 inch. If the difference is greater, the spider must be replaced.

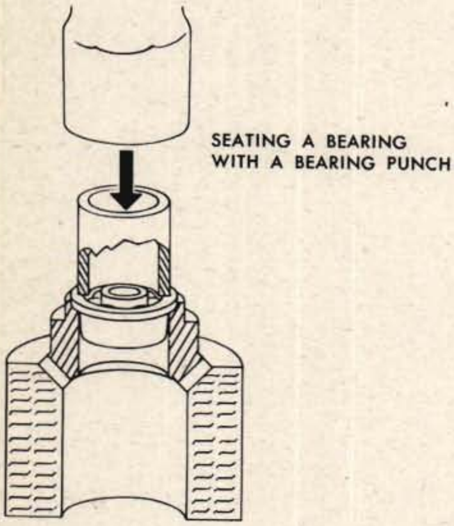
CHECKING SPIDER SQUARENESS



Removing and replacing bevel-gear bearings

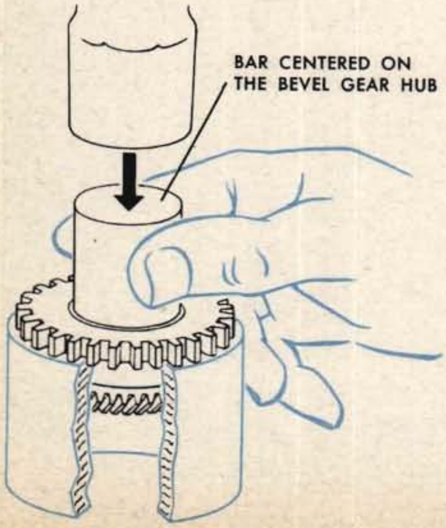


If special bearing pullers are not available, the first bearing can be started out of its seat by tapping the inner race. To avoid damaging the gear teeth, hold the gear in the hand, or place it in a conical nest of fiber or bakelite. Insert a 1/16-inch straight punch through the shaft hole in the first bearing to reach the inner race of the second bearing. Tap lightly and uniformly all around the inner race until the bearing drops out. Use a bearing punch to remove the other bearing.



Seat new bearings with a bearing punch.

Removing a spur gear from a bevel end gear

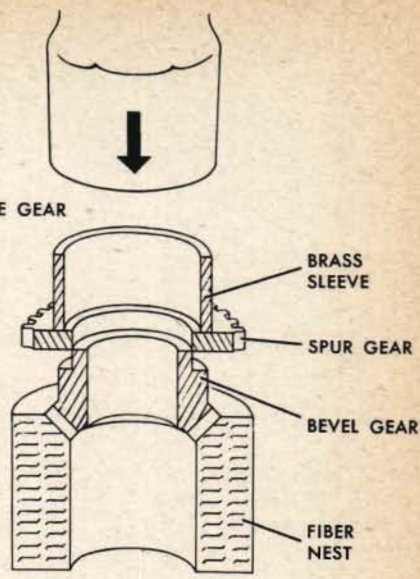


With sufficient care, spur gears can be removed without damaging the end gears. Keeping the protruding hub of the bevel gear on the top side, place the spur gear in a cylindrical nest of fiber or bakelite. To remove the bevel gear, center a brass tube or bar, slightly smaller than the hole in the spur gear, on the bevel gear hub. Tap the bar with a light hammer until the bevel gear drops out of the hole.

Replacing a spur gear or bevel end gear

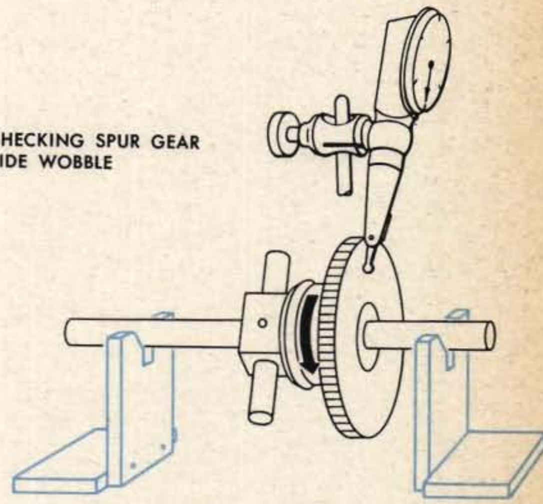
After inspecting the gear teeth to make sure there are no defects, clean both the end gear and the spur gear. Before fitting a new spur gear, remove the sharp edge from the hub of the bevel gear. Start the spur gear onto the bevel gear hub by hand. Now rest the end gear on a bakelite or fiber nest, and with a brass sleeve and a light hammer, tap the spur gear onto the hub. Make sure that the spur gear is fully seated against the shoulder on the bevel gear hub.

SEATING THE GEAR



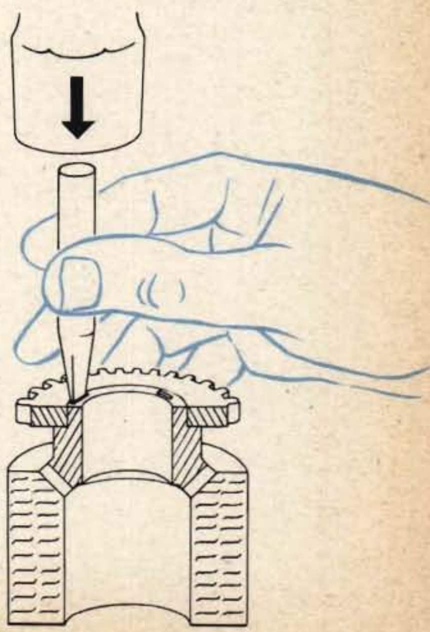
Now mount the gear assembly on the shaft, and with a dial indicator check the spur gear for wobble. If wobble is excessive, check the seating of the spur gear against the shoulder.

CHECKING SPUR GEAR SIDE WOBBLE



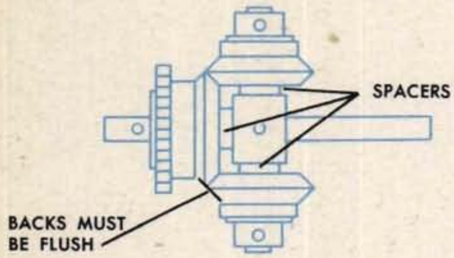
Examine the staking in an assembled differential to see how it is done. Use a sharp chisel to stake the spur gear to the bevel gear in the same way. Dowel these parts as described in the explanation of doweling, pages 74-75.

STAKING



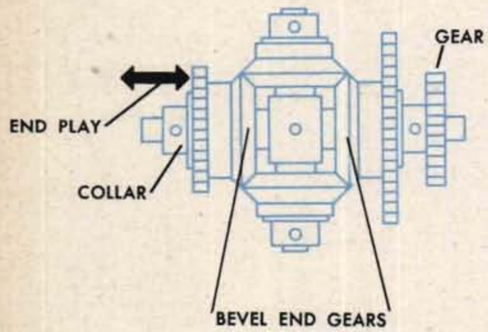
If a new end gear is used, the bearings must be fitted to it. Seat them with a bearing punch, supporting the gear in the hand or in a fiber nest in order not to damage the teeth.

Reassembling the unit



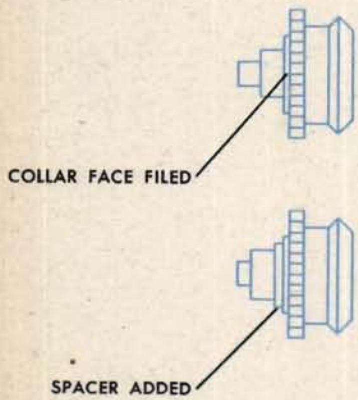
1 Using the particular spacer which belongs between each gear and the spider block, mount both spider gears on the spider arms and one end gear on the shaft. If any new parts have been used to repair the differential, new spacers may be required.

2 Fit the spacers to make the backs of the bevel gears flush and to remove nearly all lost motion. If the meshes are only *slightly* rough they can be improved by running-in the gears at step 7.



3 Now remove the first end-gear assembly and mount the other, correcting its mesh by fitting only its particular spacer. Do not alter the spider-gear spacers. When the gears mesh properly, replace the other end-gear assembly on the shaft.

4 Add the collar and the gear which position the bevel end gears, and set them carefully to avoid end play. If a new shaft is used, it is preferable to use new collars. If the original parts are used, it may be necessary to fit new spacers.

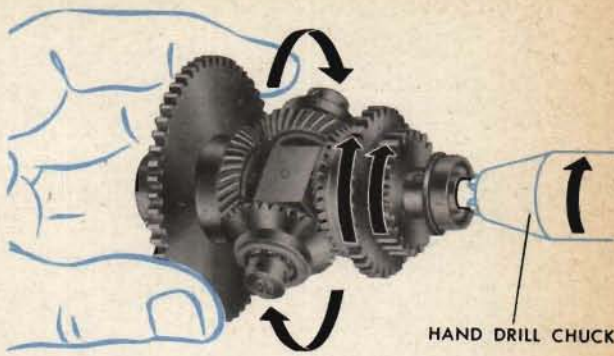


5 Insert the taper pins and tap them lightly to hold them in place. If a new shaft has been used, first drill the taper pin holes but do not ream them until step 9.

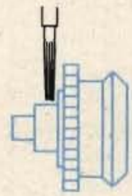
6 Check the spider gears and the bevel end gears for end play. If necessary, fit spacers to eliminate end play or file the collars to allow free running of the bearings.

7 Lubricate the four bevel gears and run them in. If necessary, coat the teeth with running-in compound, very lightly, so that it will not fly off and get into the bearings.

8 Run-in the bevel gears by rotating the shaft by hand or with a hand drill. Rotate each end gear separately for about a half-minute while holding the opposite end-gear assembly stationary. Be careful not to allow the compound to enter the bearings during this operation, and afterward wash the whole assembly thoroughly with an approved solvent.

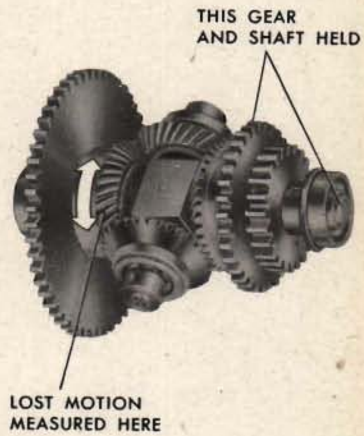


9 Finish hand-reaming each taper pin hole and fit all the taper pins. Seat the pins, but do not stake them until after all the gear meshes have been checked for smoothness and lost motion.



10 If fully seating the pins has caused any of the meshes to tighten, or has increased the end play of any gear, readjust by filing the face of the collar or by adding a spacer. All gears must be completely free on their shafts, but without end play. Each bevel gear mesh should have less than 0.0005-inch lost motion. The reassembled differential should now run freely and coast to a slow stop.

11 Use an indicator to measure the total lost motion at the pitch line of one bevel end gear when the other bevel end gear and the differential shaft are held stationary. The allowable maximum of total lost motion is shown on the assembly drawing for each differential.



12 Now stake the taper pins, making sure to support the parts directly under the staking tool. After staking, the differential should be checked for lost motion, end play, and smoothness of operation. Finally, wash and lubricate the entire differential assembly.

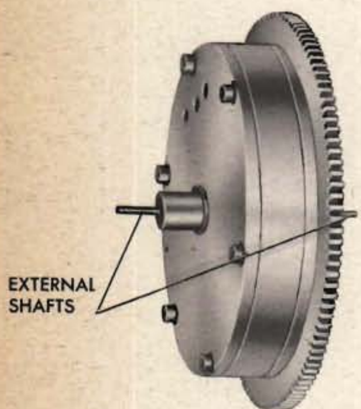
THE JEWEL DIFFERENTIAL

LARGE JEWEL DIFFERENTIAL

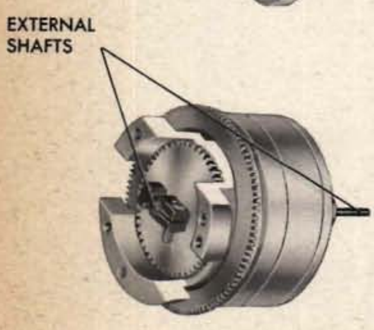
SMALL JEWEL DIFFERENTIAL

A jewel differential is a spur gear differential. It has the same function as a bevel gear differential, but is used where low inertia is required and where the load is light. Jewel differentials are usually mounted in electromechanical units. The large type is used in double-speed receivers, and the small type in the time motor regulator.

A jewel differential is a delicate piece of equipment and should always be handled with great care.



The spider is built up around the gears to form a protective case. The small steel shafts are mounted in cup bearings made of a synthetic jewel or a special steel. To protect these external shafts, the differential should always be supported on blocks so that the shafts never touch the bench.



Typical symptoms

If the operation of a jewel differential is faulty, look for one or more of these typical symptoms:

JAMMING AND STICKING: An external shaft resists turning.

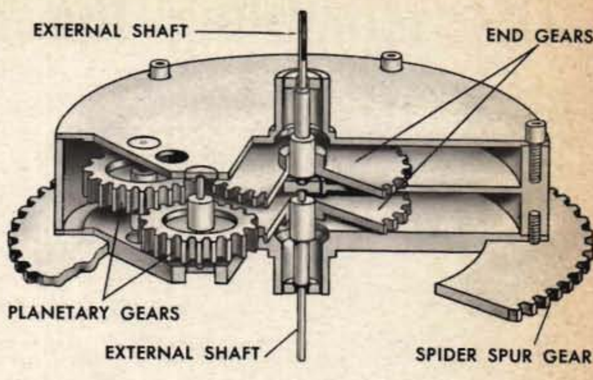
SLIPPING: When the spider and one external shaft are held, the other shaft can be turned.

EXCESSIVE LOST MOTION: When the spider and one external shaft are held, excessive lost motion can be felt in the other shaft.

Locating the cause

Four aluminum spur gears on steel shafts form the internal gearing of the jewel differential. The internal gearing should turn freely when slight torque is applied to an external shaft.

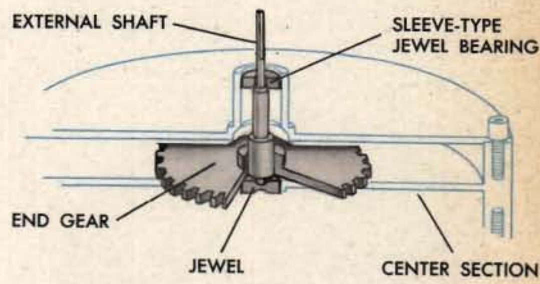
Because the gears of a jewel differential are enclosed in a case, it is often difficult to locate the cause of faulty operation. Each gear and shaft should be checked since there may be more than one source of trouble. It is advisable to remove all the gears and then reinstall each end gear singly to check its bearings and shaft. After this, reinstall each end gear with its mating planetary gear to check the gear mesh, the bearings, and the shaft of the planetary gear.



Jamming and sticking

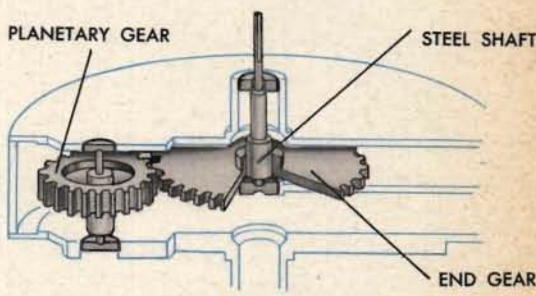
One gear alone may jam or stick because of insufficient end play, a burred pivot point, or dirty or damaged jewel bearings.

A gear may jam or stick if a jewel bearing has shifted sufficiently to allow the shaft to slip out of the cup in the jewel. A shifted jewel may allow an end gear to rub against the center section or on the side of the planetary gear with which it does not mesh.



An external shaft may bind because of damage to its shank or its sleeve-type jewel bearing.

Two meshing gears may jam or stick because of dirty or damaged teeth.

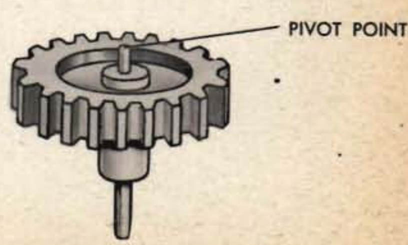


Slipping

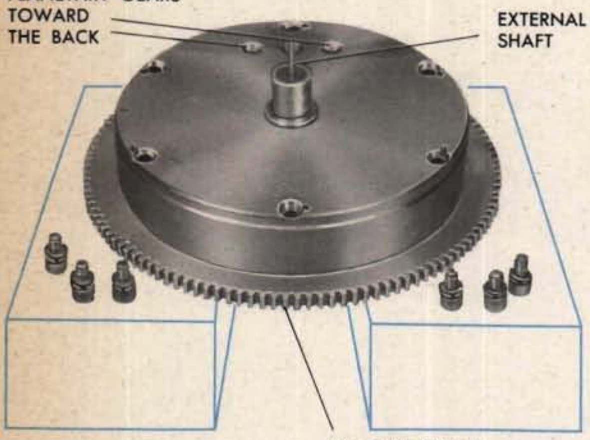
An aluminum gear may slip because it fits loosely on a steel shaft. It may slip out of mesh if its shaft pivot point is broken or if its jewel bearing has been jarred loose or shifted sufficiently to allow the pivot point to slip out of the cup in the jewel. If a gear slips out of mesh there will usually be a rough and sticky feeling when the end shafts are turned by hand.

Excessive lost motion

Excessive lost motion in the gear meshes may be caused by wear. Worn gears must be replaced. Excessive lost motion accompanied by a feeling of roughness when the end shafts are turned by hand may be caused by a broken pivot or a damaged jewel.

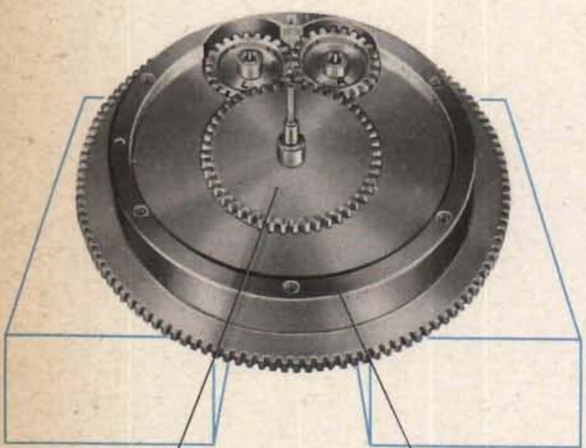


Disassembling the large jewel differential

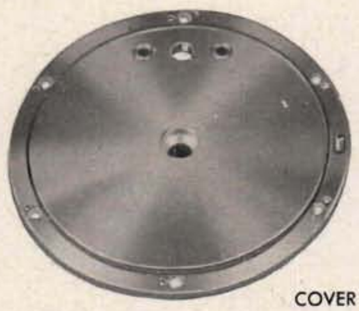


1 Support the differential on two blocks, with the cover on top and the planetary gears toward the back.

2 Remove the six screws, lock washers, and lug washers holding the cover to the center section.

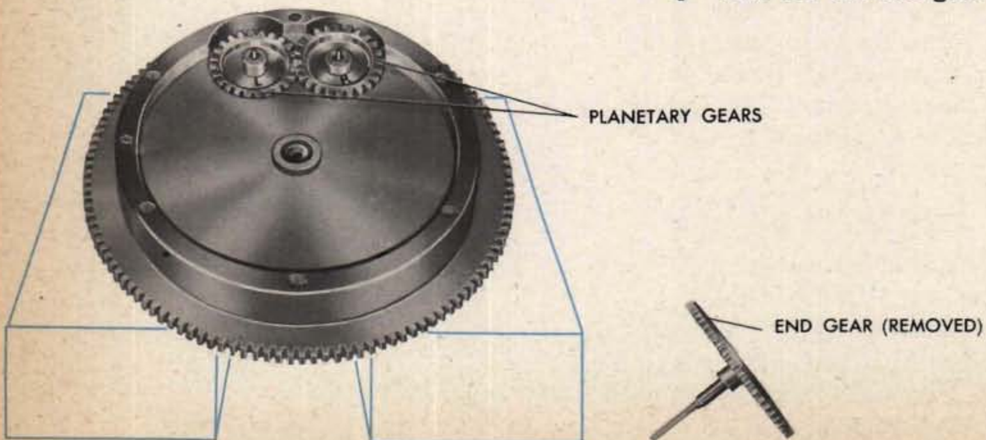


3 Remove the cover.

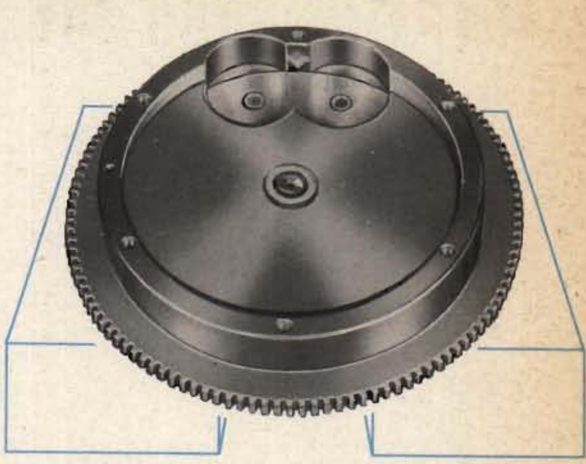


COVER (REMOVED)

4 Lift out the end gear and tag it.



5 Remove the right planetary gear. If it is not marked, tag it. The smaller hub of this gear faces the cover. (In some differentials the smaller hub of the left planetary gear faces the cover. In either case do not interchange the planetary gears.)

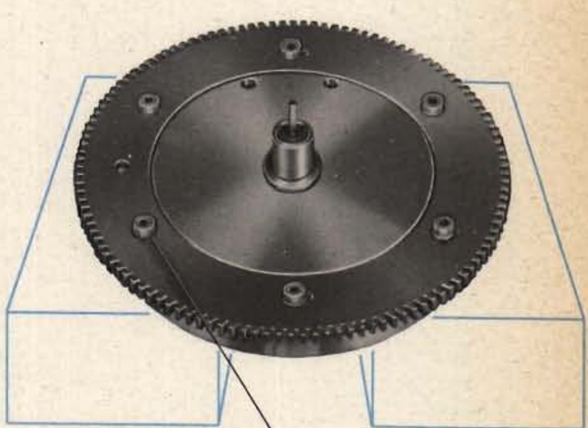


LEFT PLANETARY GEAR (REMOVED)

RIGHT PLANETARY GEAR (REMOVED)

6 Remove the left planetary gear. If it is not marked, tag it. The larger hub of this gear usually faces the cover.

7 Invert the assembly and remove the six screws holding the spider spur gear to the center section. These screws are longer than the ones holding the cover.

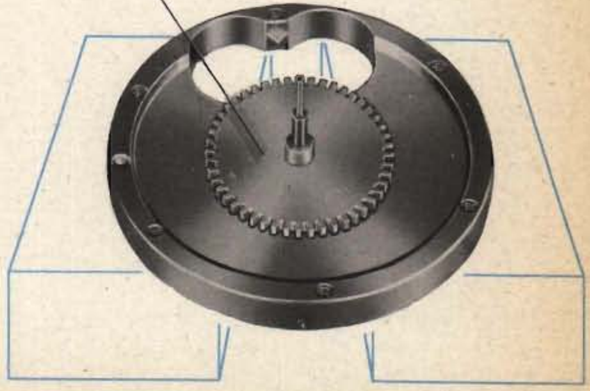


INVERT THE ASSEMBLY AND REMOVE THE SIX SCREWS

8 Remove the spider spur gear assembly which is doweled to the center section.

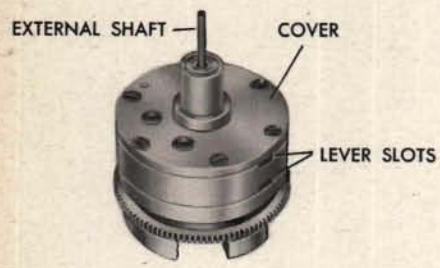
9 Remove the end gear and tag it. The shaft in this end gear is equal in length to the shaft in the other end gear, but the flat is shorter.

END GEAR



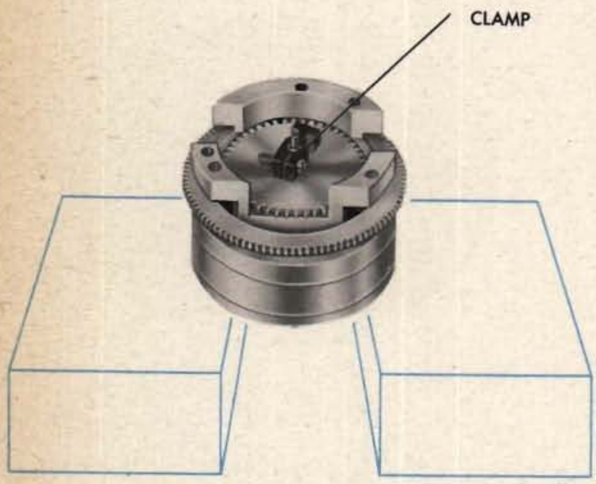
SPIDER SPUR GEAR (REMOVED)

Disassembling the small jewel differential



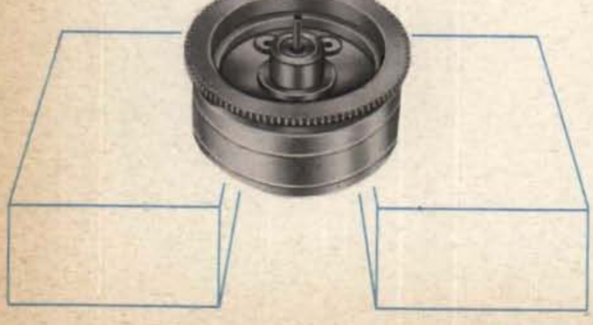
1 Remove the flat-head screws.

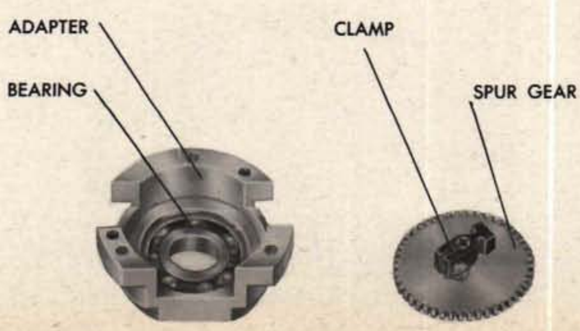
2 Invert the differential and support it on two blocks to prevent damage to its external shafts. The planetary gears should be toward the back.



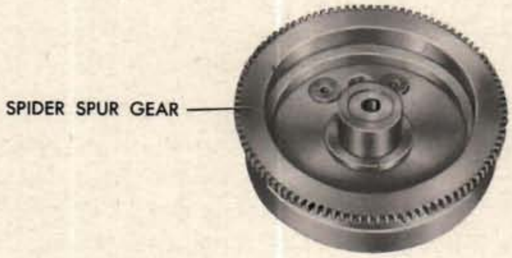
3 Loosen the clamp. Remove the clamp and spur gear together.

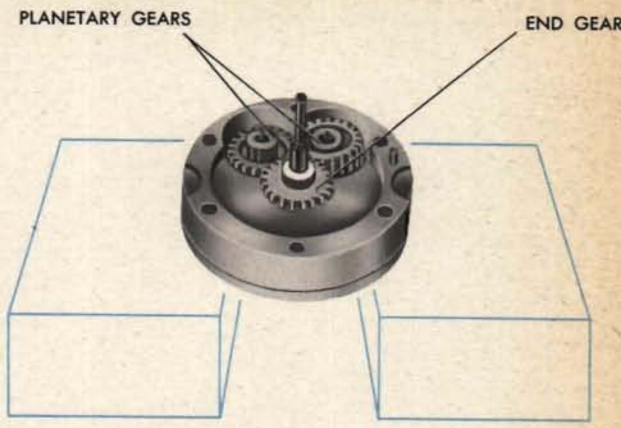
4 Remove the adapter and bearing.





5 Remove the spider spur gear.

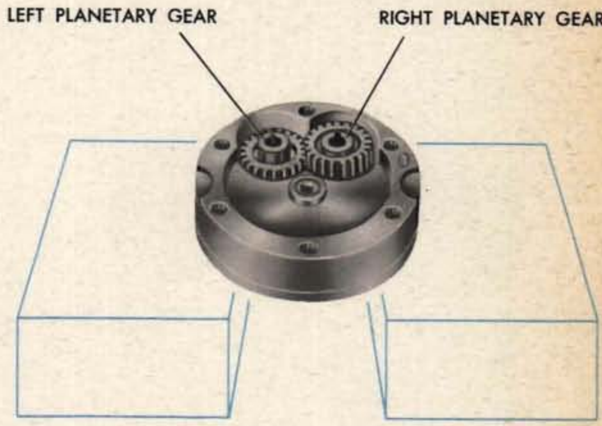


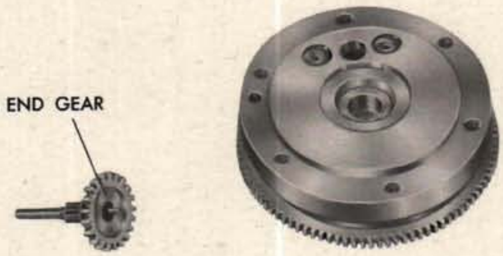


6 Lift out the end gear and tag it.

7 Lift out the right planetary gear. If it is not marked, tag it. The smaller hub of this gear faces upward.

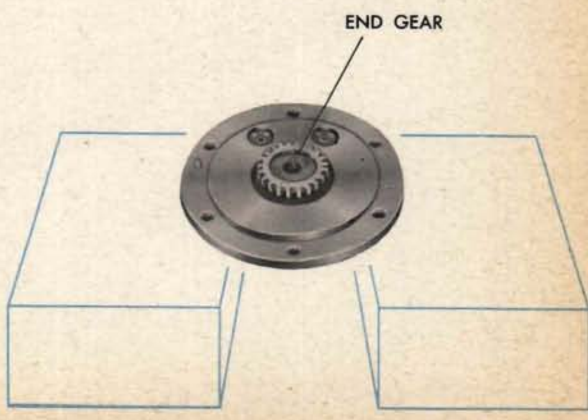
8 Lift out the left planetary gear. If it is not marked, tag it. The larger hub of this gear faces upward.

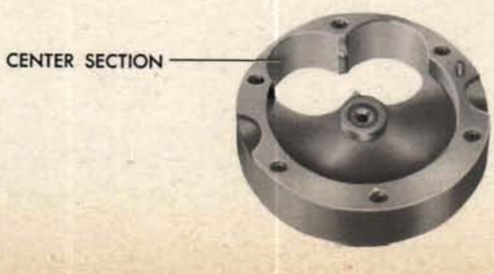




9 Remove the center section of the spider.

10 Remove the end gear from the cover.





Repairing the parts

PUNCH FOR JEWEL BEARINGS

PUNCH FOR REMOVING SHAFTS

PUNCH FOR INSTALLING SHAFTS

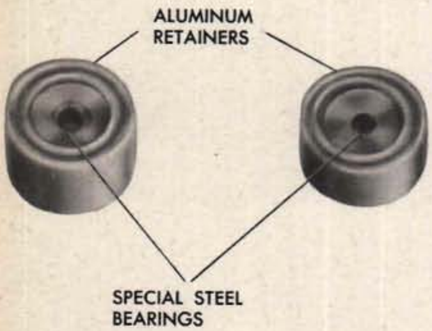
The repair procedure is the same for both the large and small jewel differentials.

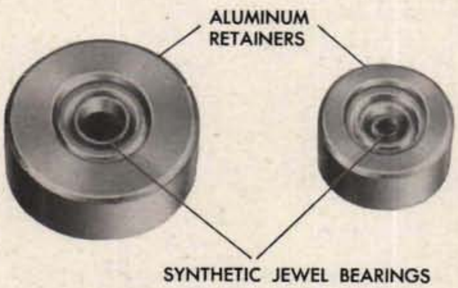
In shifting or removing a jewel bearing, use a punch that engages the aluminum retainer only and does not touch the jewel itself. In removing a shaft from a gear, use a hollow-pointed punch to fit the end of the shaft.

Shafting

To increase or decrease end play in a shaft, shift a jewel bearing. Use the special punch, and tap gently.

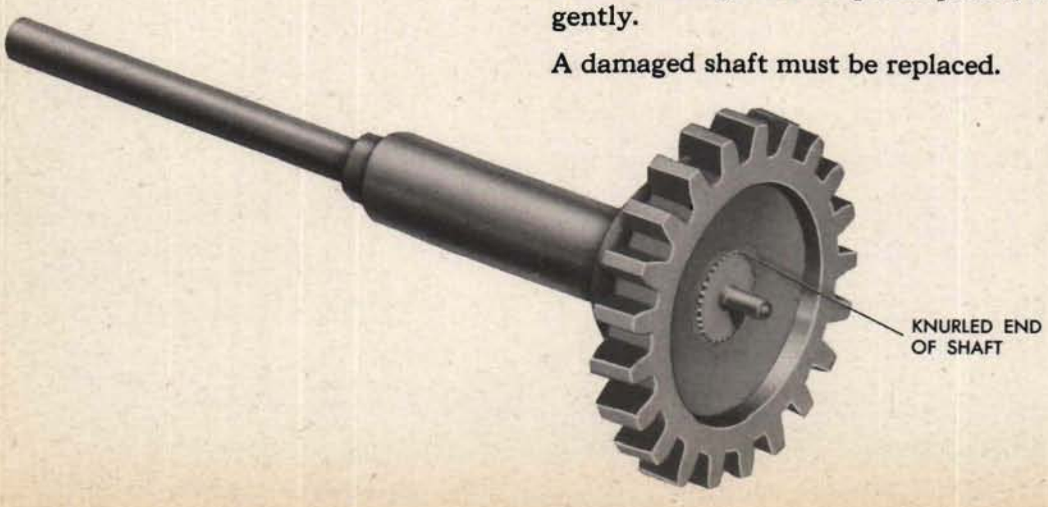
Polish a shaft that is burred, scarred, or fits too tightly in the bearing. Do not stone it.

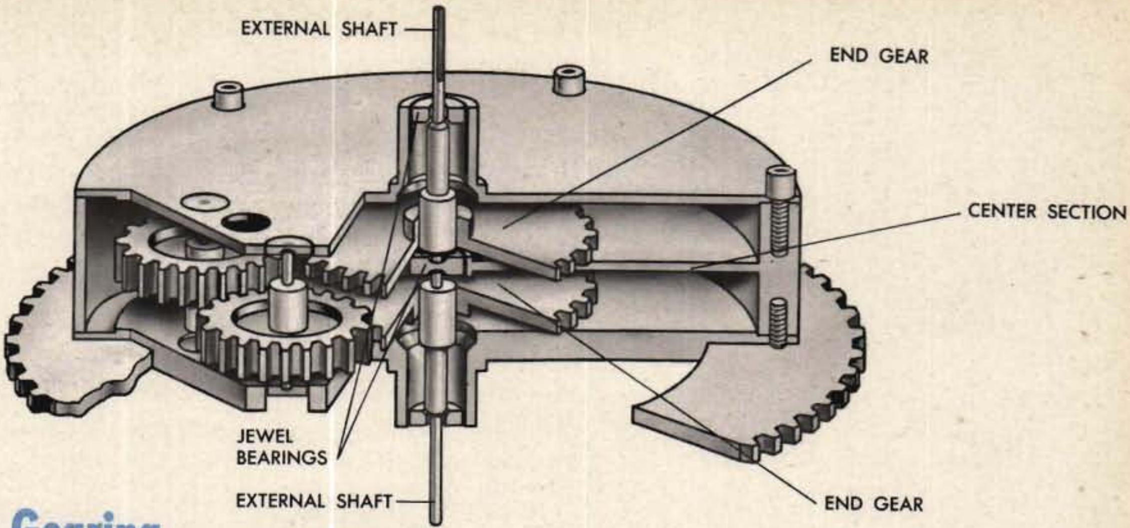




A damaged jewel bearing must be replaced. To avoid damaging a jewel when installing a new bearing, use the special punch, tapping gently.

A damaged shaft must be replaced.





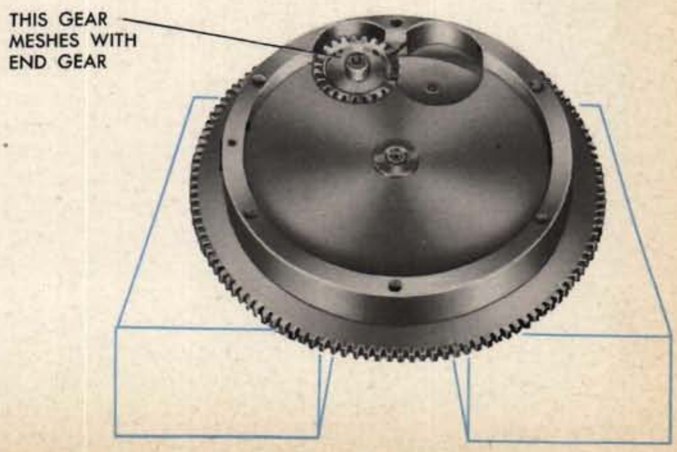
Gearing

If an end gear rubs on the surface of the center section, or on the side of the planetary gear with which it does not mesh, shift the jewel bearings of the external shafts to obtain the proper clearances.

Replace any gear with excessively worn teeth, or a gear which slips on the knurled shaft. The shaft can be used again.

If a new gear is fitted on a shaft or a new shaft is fitted to an old gear, check the gear for run-out before installing it in the differential. See Basic Repair Operations, pages 68-71.

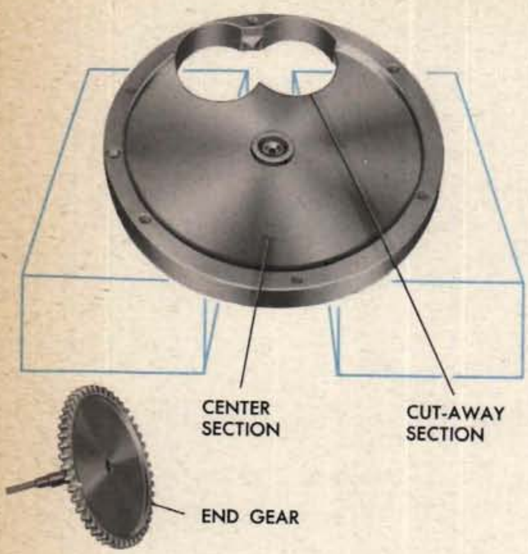
If the gears are clean and run true, but the mesh is tight, check the alignment of the cover plates to the center section. If a change is made, redoweling of the covers will be necessary. Refer to Basic Repair Operations, pages 74-75. If the mesh is still tight after redoweling, run-in two gears at a time by turning an external shaft and using a suitable running-in compound. Do not run-in the entire gearing at one time. Apply the compound carefully so that it does not enter the bearings.



Reassembling the large jewel differential

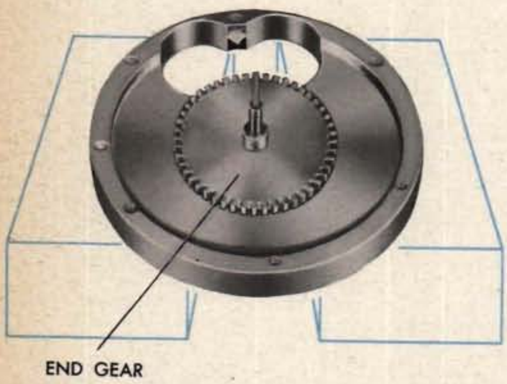
Use the assembly drawing as a guide for reassembly if it is available.

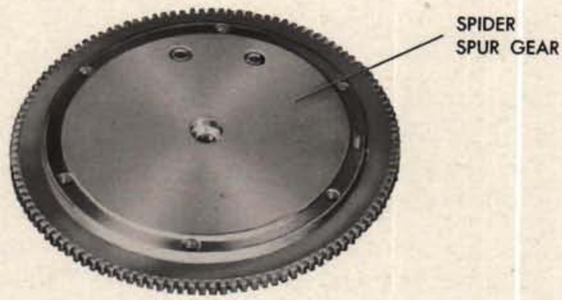
Wash all the parts with an approved solvent and dry them before beginning to reassemble the unit. Lubricate the jewel bearings with a half-drop of chronometer oil. Do not lubricate the gears. Check the mesh of each gear as it is mounted in the assembly.



1 Support the center section on two blocks with the larger dowel hole upward and the cut-away section toward the back.

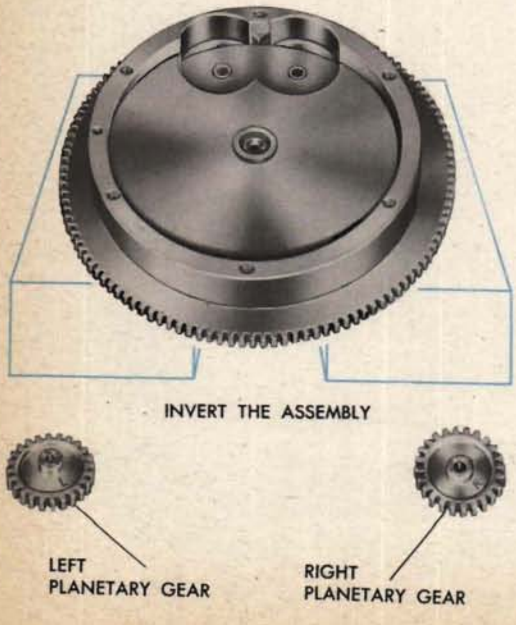
2 Mount the end gear which has the *short* flat on its shaft.



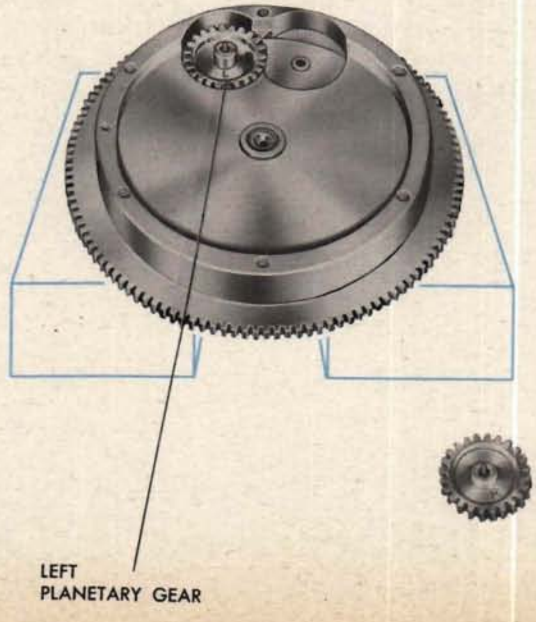


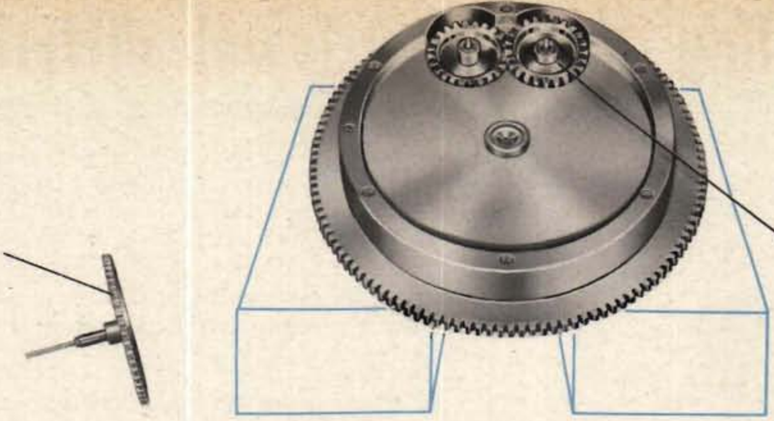
3 Mount the spider spur gear and secure it to the center section with the six long screws.

4 Invert the assembly.



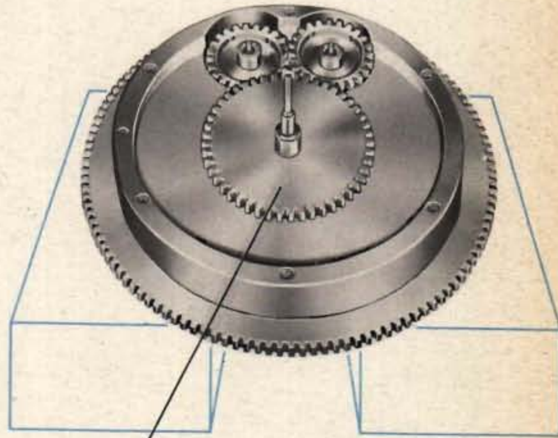
5 Mount the left planetary gear with the larger hub upward.

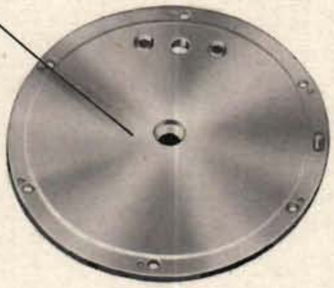




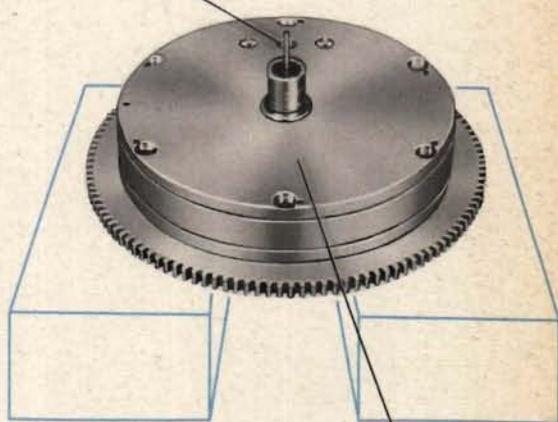
6 Mount the right planetary gear with the smaller hub upward.

7 Mount the end gear.



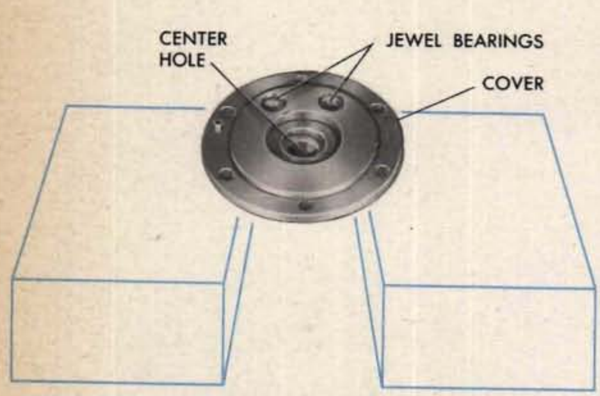


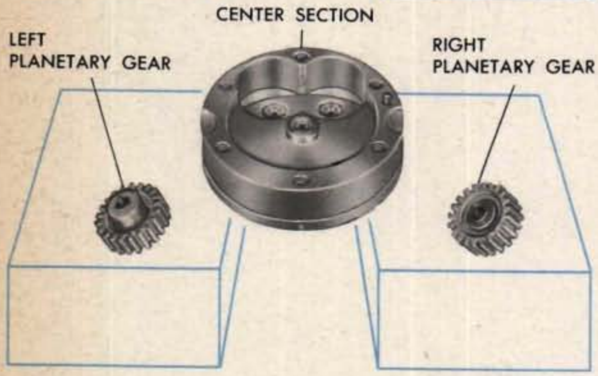
8 Put the cover in position but do not exert force to seat it. Before it can be fully seated, the planetary gear pivots must be located in their respective jewels. This can be done by working through the differential window with a pointed tool. While applying a light pressure to the cover, manipulate the gears until their pivots slip into the bearings, and then seat the cover.

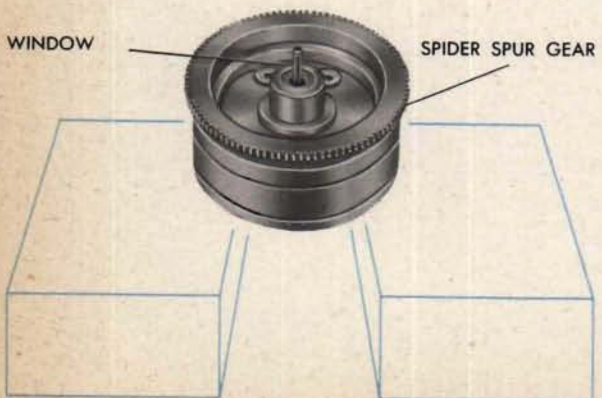


9 Put the six screws in place and tighten them.

Reassembling the small jewel differential



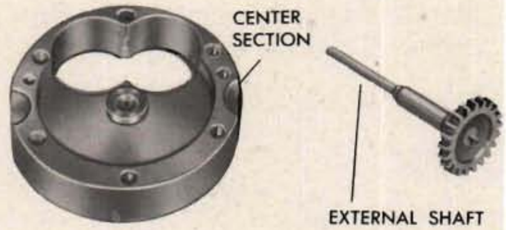




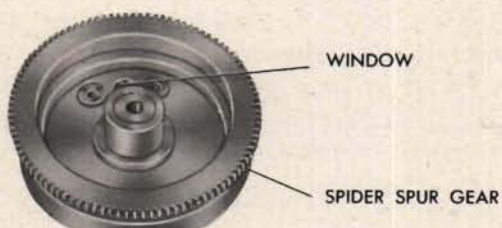
Always use the assembly drawing as a guide for reassembly.

Wash all the parts with an approved solvent and dry them before beginning to reassemble the unit. Lubricate the jewel bearings with a half-drop of chronometer oil. Do not lubricate the gears. Check the mesh of each gear as it is mounted in the assembly.

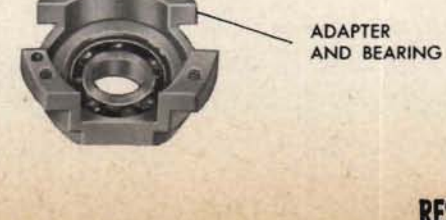
1 Support the cover on two blocks, with the two jewel bearings toward the back.

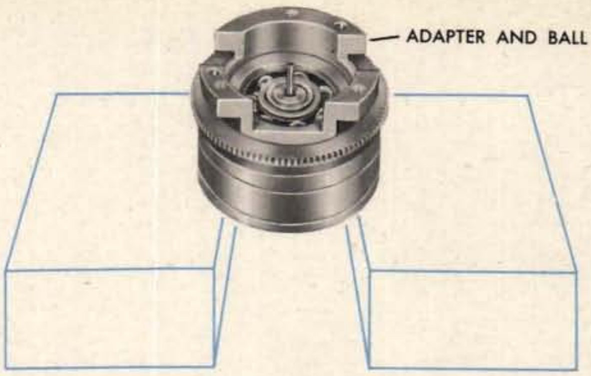


2 Mount the end gear with the longer shaft in the cover.
3 Mount the center section of the spider on the cover.
4 Mount the left planetary gear with its larger hub upward.
5 Mount the right planetary gear with its smaller hub upward.
6 Mount the other end gear.

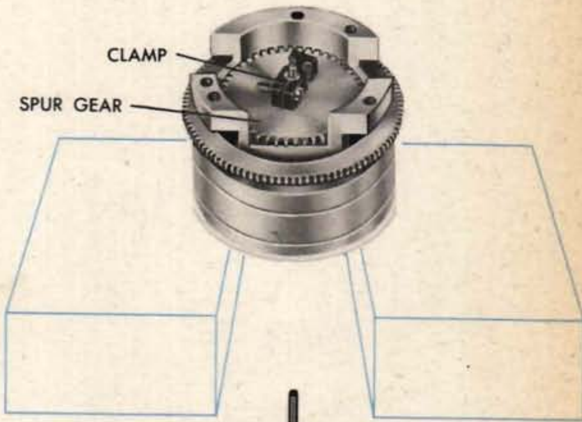


7 Put the spider spur gear in position on the center section but do not use force or attempt to seat it. Before the spider spur gear can be fully seated, the planetary gear pivots must be located in their respective jewels. This can be done by working through the differential window with a pointed tool. While applying a light pressure to the spider spur gear, manipulate the planetary gears until their pivots slip into the bearings.



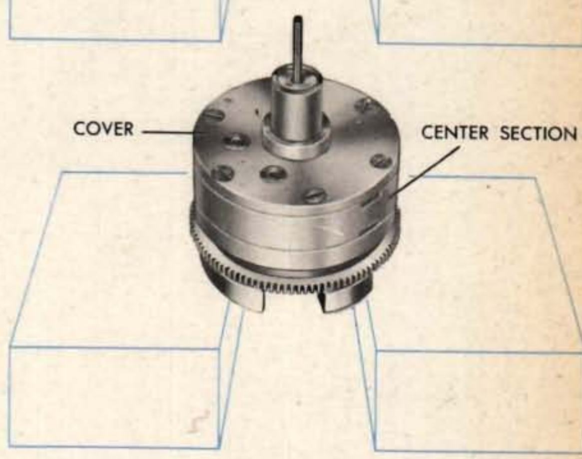


SPUR GEAR



8 Mount the adapter and ball bearing.
9 Mount the spur gear and clamp. Tighten the clamp.

10 Invert the differential. Put in and tighten the six screws.



Bench checking the unit

1 The differential must be very lightly lubricated at the pivots only. The gears must not be lubricated.

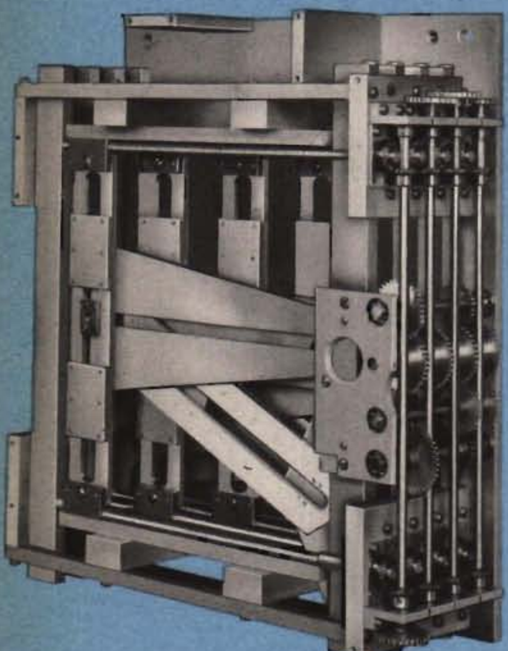
2 The spider spur gear must be clean and free of burrs.

3 The gear meshes must be free, yet have no lost motion.

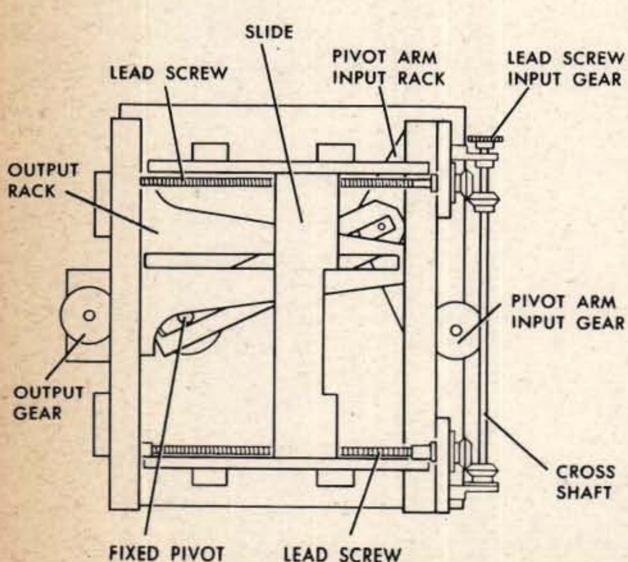
4 The shafts must have no more than 0.001 inch end play.

5 The internal gearing must turn smoothly and freely when a slight torque is applied to an external shaft.

THE SCREW TYPE MULTIPLIER



4 MULTIPLIER GROUP



Screw type multipliers are usually mounted side by side in groups of two, three, four, or more. A group of multipliers mounted in this manner forms one assembly. In such a multiplier group, the lead screw and pivot arm input gearing for all of the multipliers makes up one gearing group at one end of the assembly. At the opposite end, the output gearing of all of the multipliers makes up another gearing group.

In order to remove one multiplier, it is usually necessary to remove the input and output gearing groups. Before the gearing groups are removed, however, the trouble must be exactly located in one multiplier. If the unit must be removed for repair, consult the instrument OP for instructions.

Typical symptoms

If a test analysis and unit check tests have indicated that a screw type multiplier is not operating normally, look for the following typical symptoms:

LEAD SCREW INPUT – JAMMING or STICKING: The lead screw input gear cannot be turned by hand, resists turning past a certain point or points, or turns sluggishly.

LEAD SCREW INPUT – EXCESSIVE LOST MOTION: There is too great a lag between the turning of the lead screw input gear and the movement of the traveling slide.

LEAD SCREW INPUT–SLIPPING: Turning the lead screw input moves the traveling slide only intermittently.

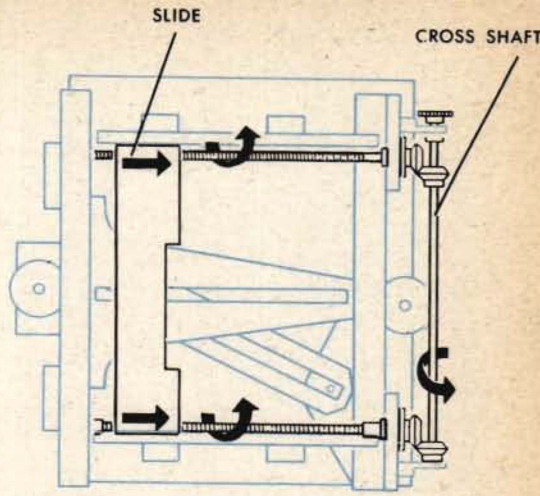
RACKS – JAMMING or STICKING: The input rack cannot be moved by hand, resists moving past a certain point or points, or moves sluggishly.

RACKS – EXCESSIVE LOST MOTION: There is too great a lag between the moving of the input rack and the moving of the output rack.

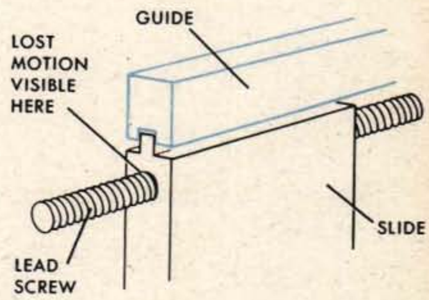
RACKS – SLIPPING: Moving the input rack does not move the output rack.

Locating the cause

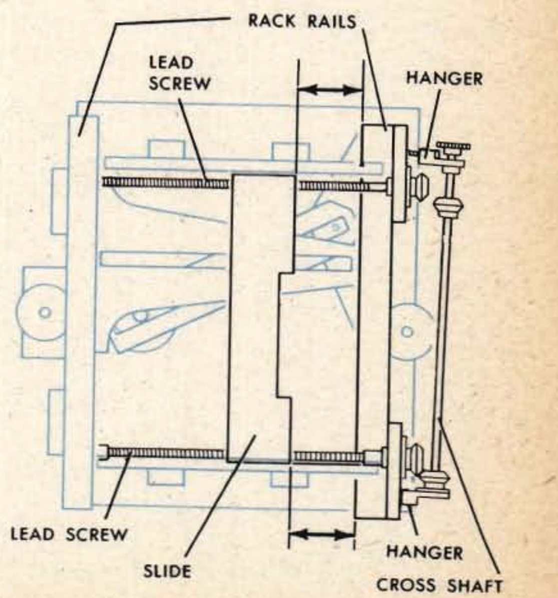
Lead screw input: jamming or sticking



The lead screw input may resist turning because the slide is jammed against the limit of its travel. If the sticking or jamming occurs when the slide is somewhere between the limits of travel, the source of trouble may be a bent lead screw, dirty or damaged lead screw threads, or dirty or damaged guides. Also, the lead screw input may jam or stick because of dirty or damaged gears or bearings in the input gearing, or because of slide blocks sticking in the rack slots.

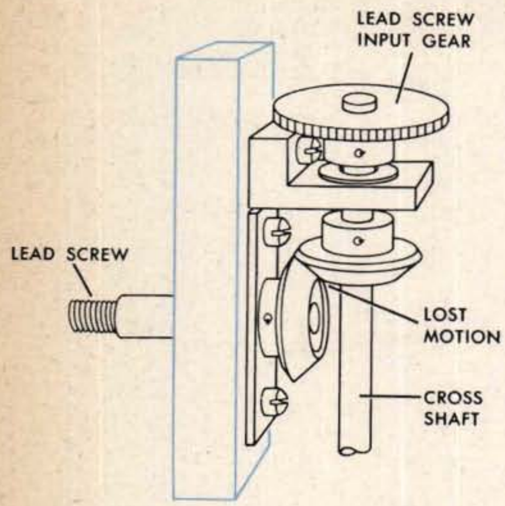


If the lead screw has jammed the slide against the limit of its travel, it can usually be backed out by hand. Try to move it by turning the lead screw input gear. After it comes free, run the slide through its full travel to be sure that the lead screw threads are undamaged. Jamming of the slide into one of its limits is the result of an incorrect limit stop adjustment. Directions for readjusting the limit stop are given in the instrument OP.



If the slide sticks or jams at some point within its normal travel, examine the lead screw threads and the guides for damage. Check the freedom of the lead screw in the slide and the slide in the guides. Even though these parts are made so that they fit very snugly, there should be a little lost motion. Absence of lost motion points to the location of the source of sticking or jamming. A damaged guide or a slightly damaged lead screw usually can be repaired, but a badly damaged or bent lead screw should be replaced.

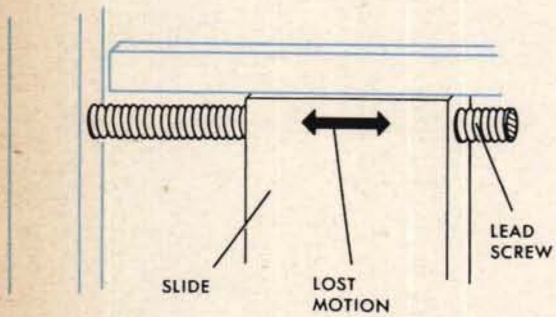
If the slide sticks all along its travel, the slide may be askew. A loose cross-shaft hanger may have permitted one of the bevel gears on the cross shaft to slip with respect to its mating gear on the lead screw. In order to correct this condition, unmesh one pair of bevel gears and turn one of the lead screws until the slide is parallel to the rack rails. Remesh the gears and secure the hanger in place.



Lead screw input: excessive lost motion

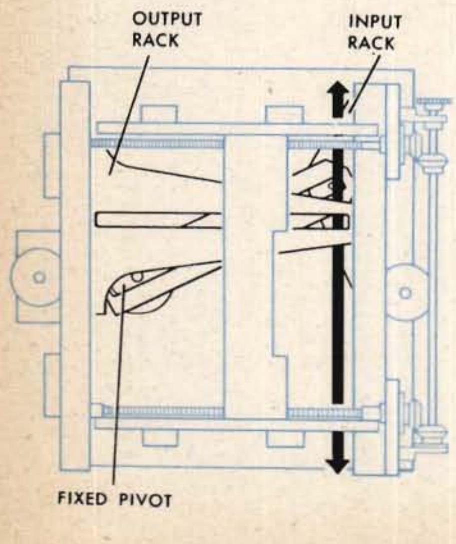
Excessive lost motion may be the result of worn bevel gear teeth, lead screw threads, or excessive end play of either the lead screw or the cross shaft.

Inspect the parts to locate the points of wear. The combined lost motion of the slide and the end play of the lead screw should be less than 0.0015 inch. Therefore, if the lost motion between the slide and one of the screws approaches this figure, replace the screw. Usually, lost motion between the bevel gears—which should average 0.001 inch—and end play of the cross-shaft or a lead screw can be eliminated by shifting hangers and changing spacers. Follow the method given in the chapter on *Shaft Lines*.



Lead screw input: slipping

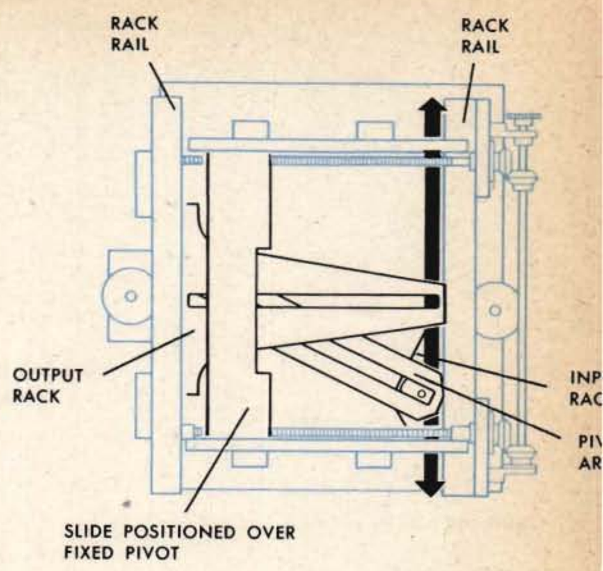
Slipping may be the result of a sheared or missing taper pin in the bevel gears or of stripped lead screw threads. Replace a missing taper pin. The other casualties mentioned usually mean deformed or broken parts which should be replaced.



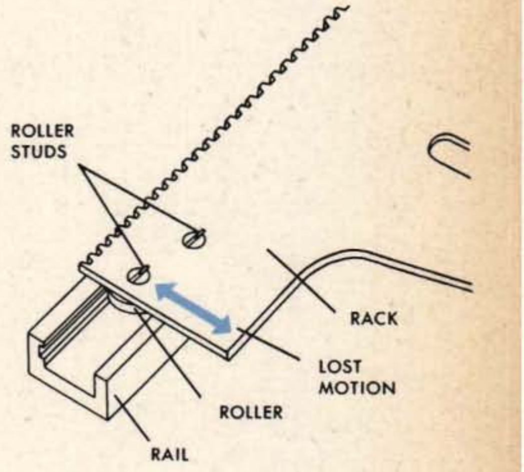
Racks: jamming or sticking

Move the input rack through its full travel and check the smoothness of operation. If the input rack jams, or if any sticks are felt, the trouble may be in either the input or the output rack.

Position the slide over the fixed pivot so that there is no motion of the output rack when the input rack is moved. Now, if the input rack travels smoothly and freely, the trouble probably is in the output rack or its related parts. The source of trouble may be dirty or damaged output rack rollers, bent roller studs, a dirty or damaged roller path in the rack rail, or a tight mesh between the output rack and the output gear. However, if there is no trouble in the output rack, then the slide block may be jamming or sticking in its slot in the slide.

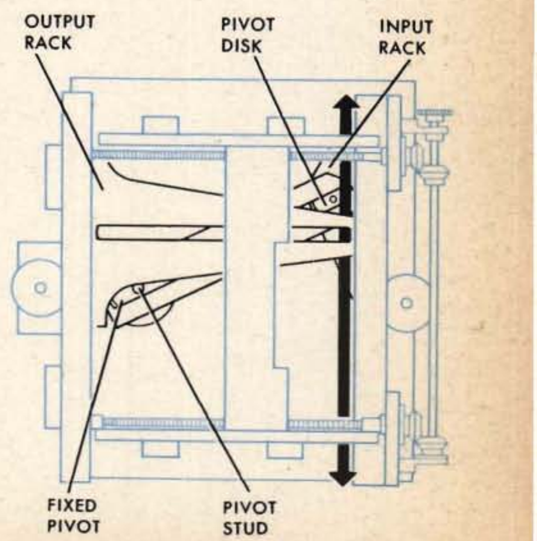


If when the multiplier stud is over the fixed pivot, the input rack jams or sticks, the trouble is in the input rack or its related parts. The source of trouble may be where the pivot arm pivots on the input rack, on the multiplier stud, or on the fixed pivot; as well as dirty or damaged input rack rollers and roller studs, a dirty or damaged roller path, or a tight input gear mesh.



Racks: excessive lost motion

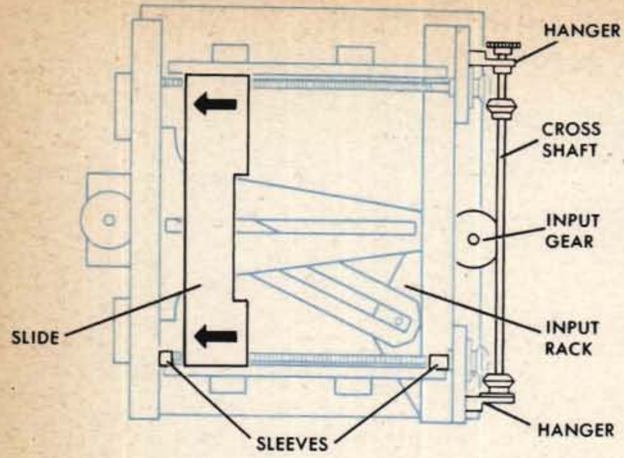
Excessive lost motion between the slide, the input rack, and the output rack may be caused either by bent or loose roller studs or by a worn slot. Loose roller studs can be tightened by riveting and the rollers adjusted in order to reduce lost motion. Bent studs and parts with worn slots cannot be repaired; they should be replaced.



Racks: slipping

When the slide is not positioned over the fixed pivot; if moving the input rack does not move the output rack, a pivot stud is broken.

To install a new pivot stud, the multiplier should be removed from the instrument.



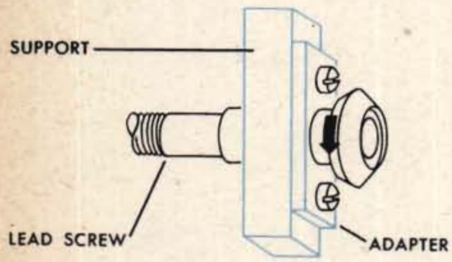
Disassembling the unit

For the sake of clarity, most of the following illustrations were drawn with only the top multiplier visible.

1 Move the slide away from the cross shaft to the limit of its travel.

2 Remove the input gear meshing with the input rack.

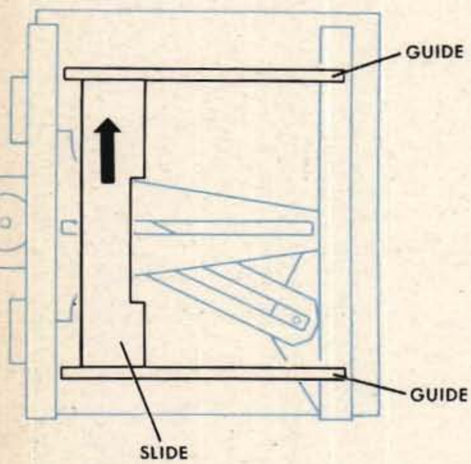
3 Remove the cross shaft assembly by taking out the hanger screws.



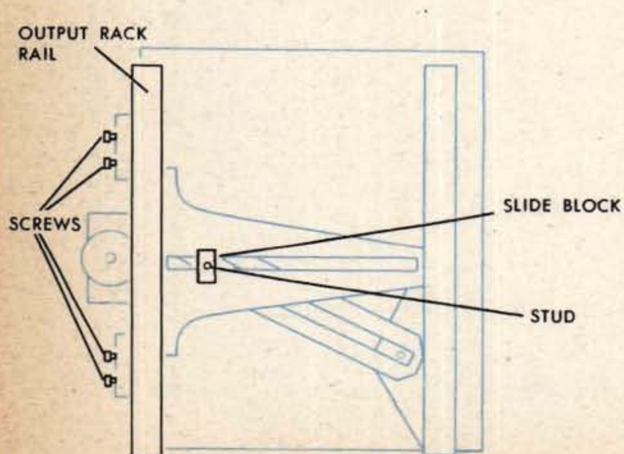
4 Remove the screws securing the lead screw adapters.

5 Turn the lead screws to back them out of the slide and to push the adapters out of their supports. Tag the two sleeves noting their positions on the lower lead screw.

CAUTION:
The adapters are doweled. Do not forcibly "jack" one off with the lead screw because damage to the lead screw may result. If an adapter does not come off easily, use a thin, sharp wedge to start it off the dowels.

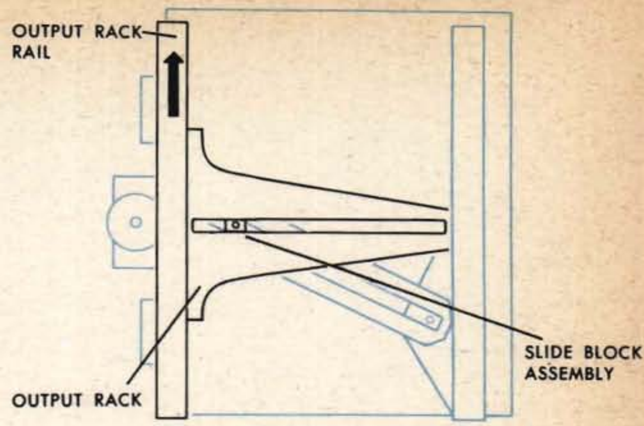


6 To remove the slide, first remove the guides. Then pull the slide off its block by moving it in the direction shown by the arrow.



7 Remove the slide block and, for safe keeping, replace it in the slide just removed.

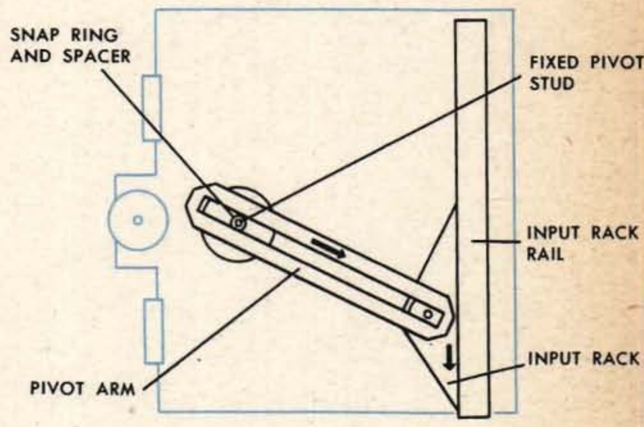
8 Remove the screws holding the output rack rail.



9 Slide off the output rack rail.

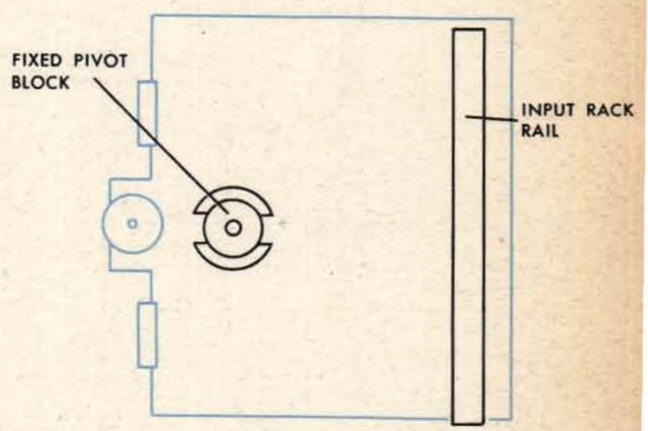
10 Lift off the output rack.

11 Note the way the slide block assembly is mounted in the input and output rack slots. Lift the blocks out.



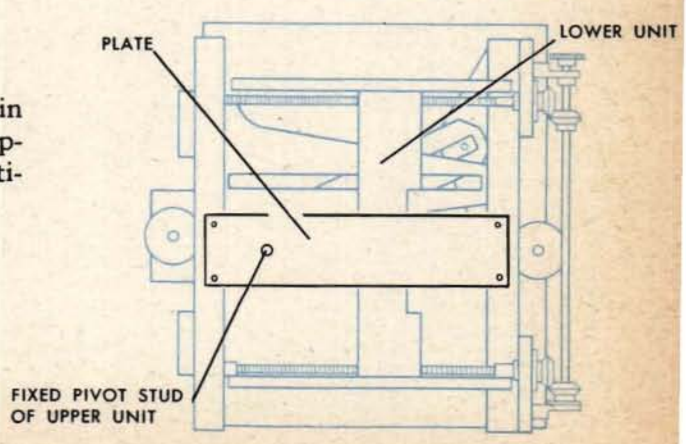
12 Remove the snap ring and spacer from the fixed pivot stud.

13 Slide the input rack off the end of its rail. The pivot arm will slide out of the pivot block if the pivot block is raised slightly so that the arm will clear the stud.

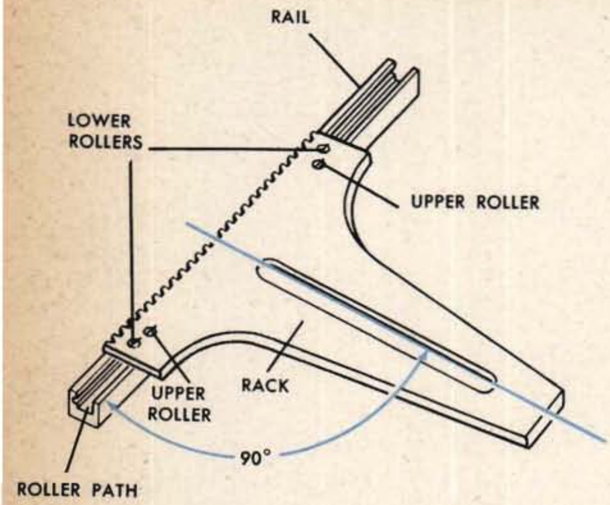


14 Lift off the fixed pivot block.

15 Remove the screws holding the input rack rail and lift off the rail.



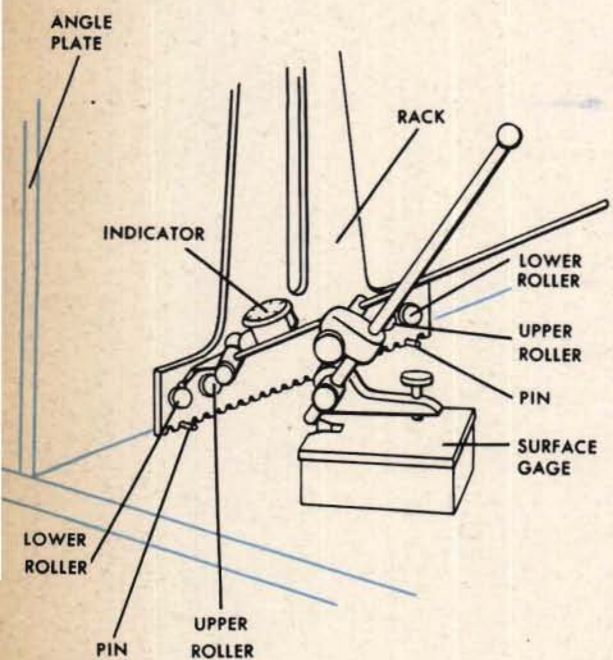
16 To disassemble the next multiplier in the group, remove the plate which supports the fixed pivot stud of the multiplier just disassembled.



Repairing the parts

Repairing a rail

First clean the roller path in the rail, and look carefully for embedded foreign materials. Polish any rough or high spots, and try the rack in the rail frequently until a good fit is obtained. After completing this work, wash all parts thoroughly with an approved solvent.

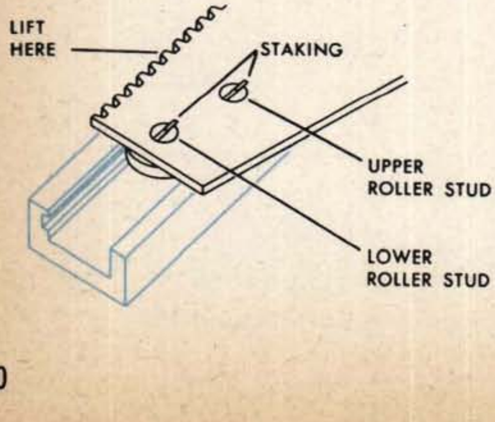


Adjusting the rollers

The lower rollers establish the pitch line of the rack in relation to its meshing gear. These rollers also affect the squareness of the rack to the rail. Remove the rack and mount it against an angle plate on a surface plate. Support the rack under the teeth, using two identical pins between 0.070 inch and 0.075 inch in diameter. Place a pin at each end of the rack.

With a surface gage and a dial indicator, measure the height of the lower rollers. The heights of these rollers must agree with the assembly drawing and be within 0.0002 inch of each other.

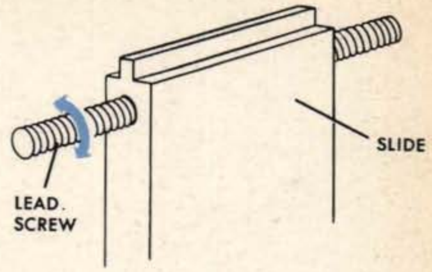
The upper rollers control the play between the rack and the rail. If the play exceeds 0.0005 inch, turn the roller studs with a screw driver. A strip of feeler-gage material (0.001 inch) can be used as a "not go" gage to check the clearance between the roller and the roller path. After positioning the rollers, stake a small amount of metal into the screw-driver slots of the stud heads. The rollers should be free enough in the rail for the rack to drop back of its own weight if it is raised slightly with one finger.



For an explanation of removing and replacing a riveted stud, see pages 76-79.

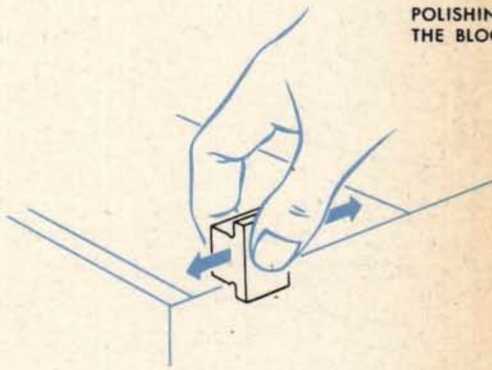
Fitting a new lead screw

Inspect the threads of a new lead screw for dirt or damage. Grease the lead screw and turn it carefully into the threaded hole in the slide. Do not force the lead screw. Turn it into the threaded hole along its full length and then back it out to check smoothness of operation. Remove the lead screw before fitting the bearings and the bevel gear. Then wash all parts thoroughly in an approved solvent.

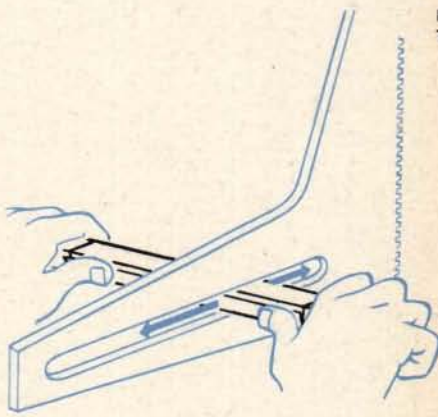


Fitting a new slide block

Use a fine oilstone to smooth burred or rough edges of a new block. Remove any extremely sharp edges, but leave the block square. It is very important not to round or chamfer the edges.



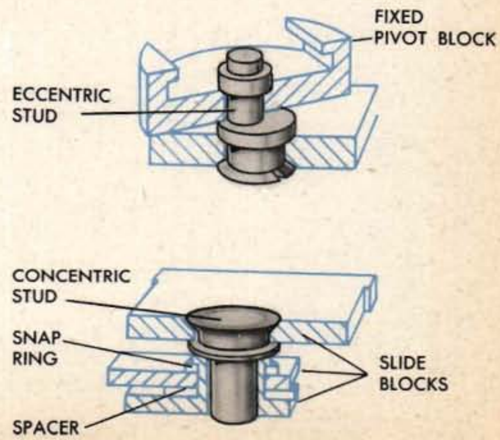
To reduce the width of a block, polish the sides on a piece of crocus cloth placed on a flat surface. Use long, even strokes while holding the block square. Be sure to remove equal amounts from both sides so that the hole remains centered. Measure the block occasionally with a micrometer to be certain that the sides are parallel.



Polish the block until it fits the widest portion of the slot without lost motion. Using crocus cloth over a steel bar, polish the rest of the slot to fit the block. Be sure to keep the slot sides square and flat.

Remove the block from the slot, clean both parts thoroughly, and lubricate them. Fit the block into the slot and move it back and forth until it travels smoothly along the entire length of the slot.

Replacing a pivot stud



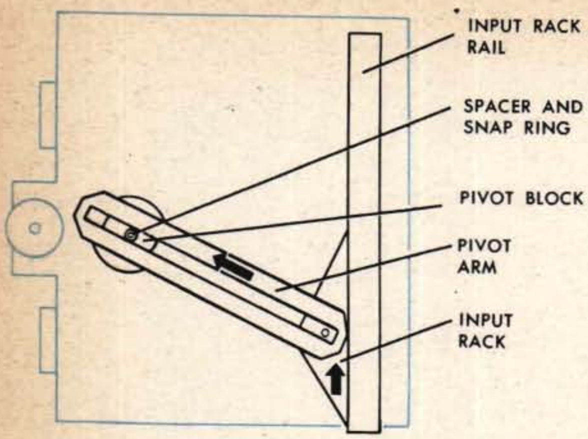
Following the instructions on riveting, pages 76-79, drill out and replace the stud. The fixed pivot stud is eccentric. Consult the assembly drawing and adjust the stud at the indicated distance from the multiplier pivot disk.

The multiplier stud in the slide is concentric and does not require adjustment.

Reassembling the unit

Wash all the parts with an approved solvent and dry them before starting to reassemble the unit. Lubricate each part before replacing it. After mounting each part, check the operation of all parts for smoothness and proper lost motion.

If the multiplier is to be assembled on top of another multiplier, first replace the plate which supports the fixed pivot stud.

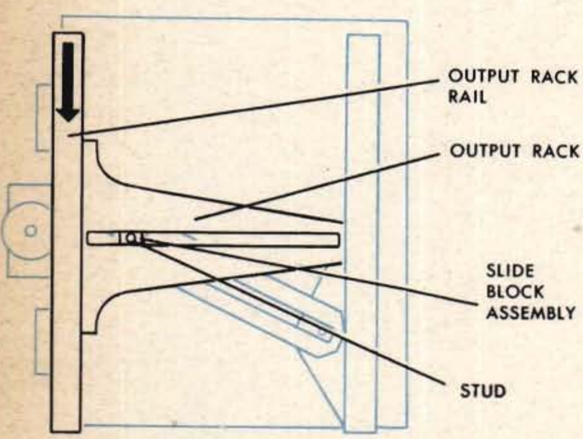


1 Replace the input rack rail.

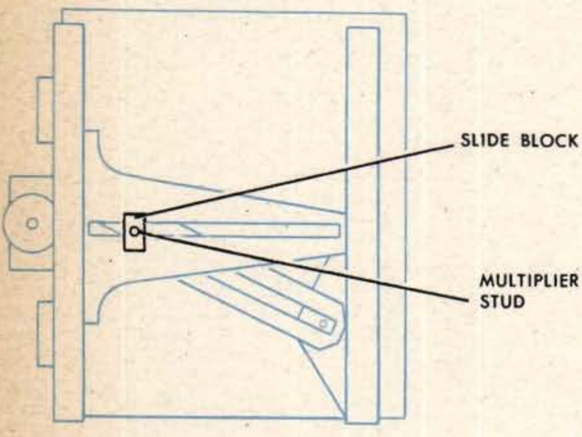
2 Replace the pivot block on the stud

3 Raise the pivot block slightly, and slide the pivot arm into it. At the same time, slide the input rack onto its rail.

4 Replace the spacer and snap ring.

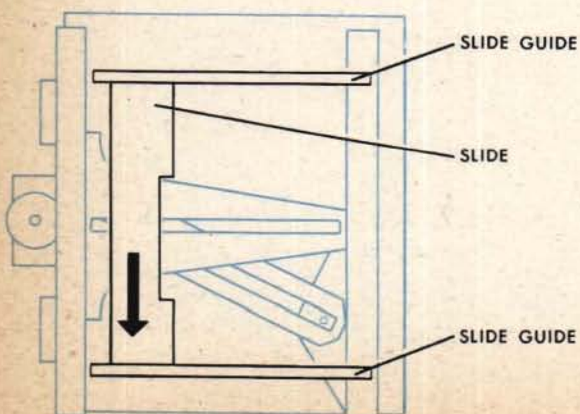


5 Replace the slide block assembly in the pivot arm slot. Be sure that the blocks are in the order indicated on the assembly drawing.



6 Put the output rack in position. Slide the output rack rail on the output rack rollers, and secure it in place. The mesh between the output rack and output gear should be free, yet have minimum lost motion.

7 Insert the multiplier stud in the slide block assembly.



8 Push the slide onto its block.

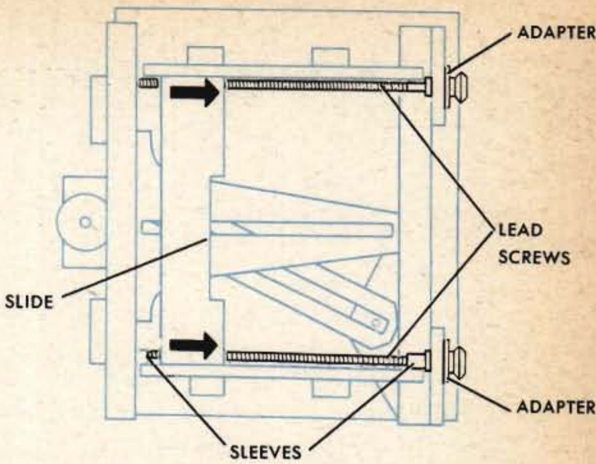
9 Replace the slide guides.

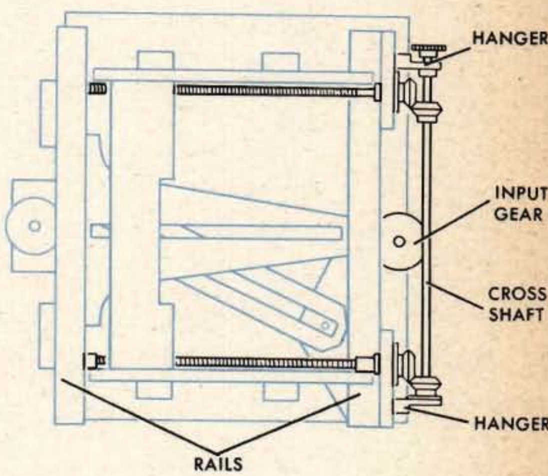
10 Insert the lead screws through the holes in the adapter supports. Replace the long sleeve on the lower lead screw. As there are four threads on each lead screw, start the lead screw into the slide in different positions until the one with the smoothest rotation is found. Replace the short sleeve on the lower lead screw.

11 Insert the ends of both lead screws into the holes in the input rack rail; then secure the adapters in their supports.

12 Replace the cross shaft, making the gear meshes so that the slide is parallel to the rack rails. Refer to the assembly drawing for the tolerances. Position the cross-shaft hangers for the minimum amount of shaft end play and lost motion.

13 Replace the input gear. Its mesh with the input rack should be free, yet have minimum lost motion.





Bench checking the unit

1 Check the assembly of the multiplier against the assembly drawings.

2 All gears should mesh freely with less than 0.001 inch lost motion.

3 The lead screw should be free to turn through the entire travel of the slide.

4 The combined end play of the lead screw and the slide should not exceed 0.0015 inch.

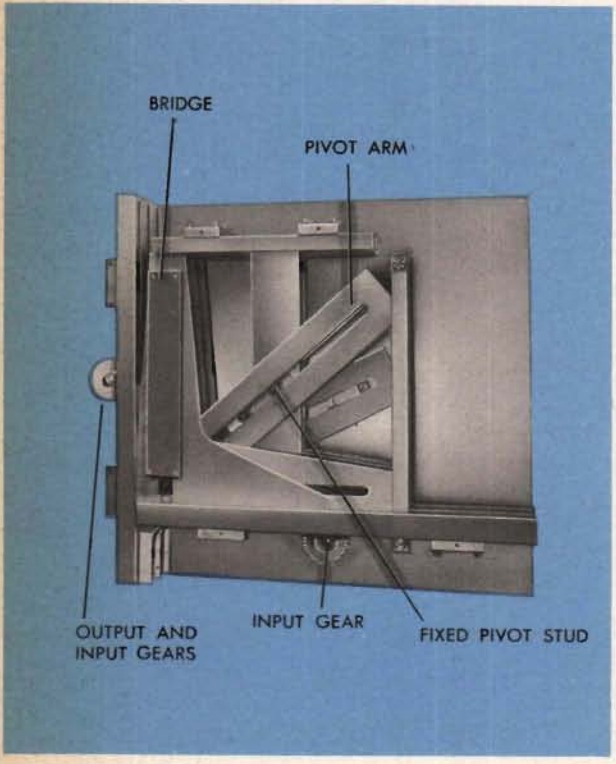
5 The racks should mesh properly with their gears throughout their entire travel.

6 All eccentric studs in the racks and bridges should have been staked.

7 Lost motion between the input and output racks and the slide should be at a minimum. Refer to the assembly drawing.

8 Make sure that the rails and the traveling slide are parallel. Place the slide at one end of its travel. Moving the input rack through its entire travel should not move the block in the output rack.

THE RACK TYPE MULTIPLIER



A rack multiplier is usually mounted on a base plate with gearing groups and other units. Occasionally one may be mounted on a separate base plate. It can seldom be disassembled in the instrument because other units near by do not allow enough space. For instructions on removing the unit from the instrument, consult the instrument OP.

The rack type multiplier has two input racks and one output rack. One input rack has a slot covered by a plate referred to as a bridge. The other input rack is joined to a pivoted arm. The output rack is between the two input racks.

Typical symptoms

If a test analysis and unit check test indicate that a rack multiplier is not operating normally, look for one of the following typical symptoms:

JAMMING: One or more racks will not move at all.

STICKING: One or more racks resist moving past a certain point or points, or move sluggishly.

EXCESSIVE LOST MOTION: There is too much play between the input and output racks.

SLIPPING: Moving the input rack moves the output rack only intermittently, or not at all.

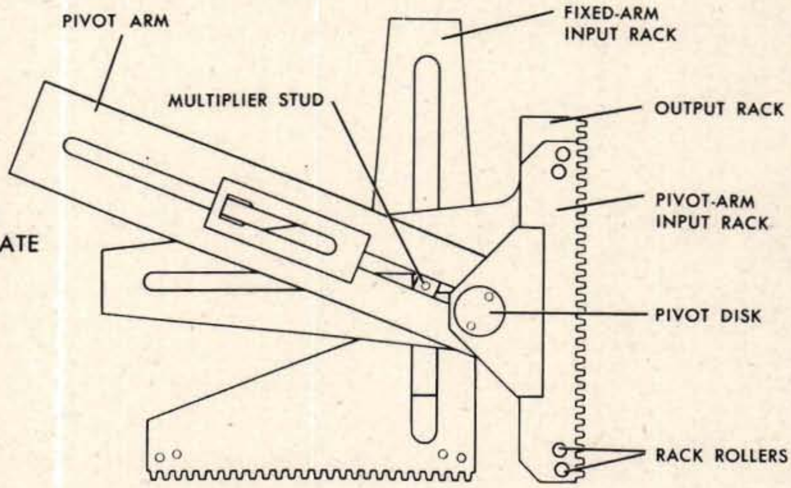
Locating the cause

Jamming

Try to move the pivot-arm input rack through its full travel. If it will not move, try to move the fixed-arm input rack. If neither input rack can be moved, the slide blocks may be binding in their slots.

If only the fixed-arm input rack can be moved, the block in the pivot arm slot may be frozen on the fixed pivot stud, the multiplier stud may be frozen in its slide blocks, the pivot disk in the pivot-arm input rack may be frozen, or the rollers on the pivot-arm input rack may be binding in their rail.

If the fixed-arm input rack is jammed when the pivot-arm input rack is held but is free to move when the pivot-arm input rack is free to move, the output rack rollers are probably jammed in their rail.



POSITION OF RACKS AS VIEWED FROM PLATE

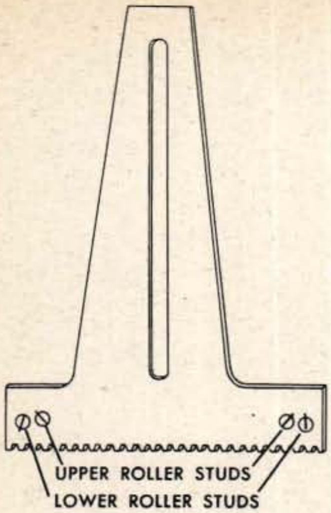
Sticking

The same methods that are used to locate the causes for jammed racks may be used when the racks stick.

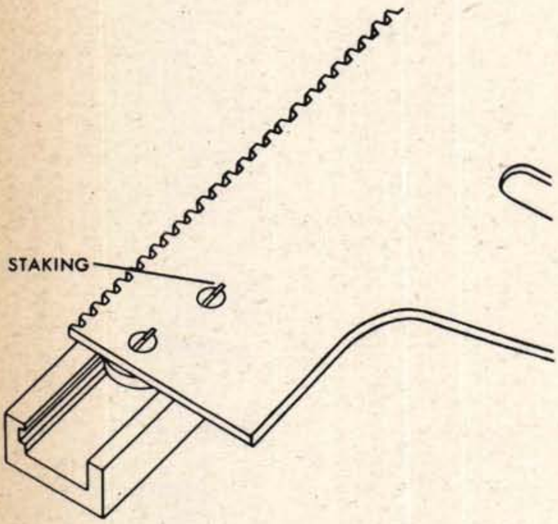
Shake the racks to check for lost motion on the rails. Incorrect adjustment between the rack rollers and the rack may cause a tight mesh between the rack and its meshing gear. The racks may also stick because of dirty or damaged teeth in the rack or gear.

Disassemble the unit for repair only if the racks stick enough to cause serious errors in the operation of the instrument. Slight sticking in the rack slots can be eliminated by cleaning the sliding surfaces. Then lubricate the unit and run the sticking parts back and forth by hand.

Excessive lost motion

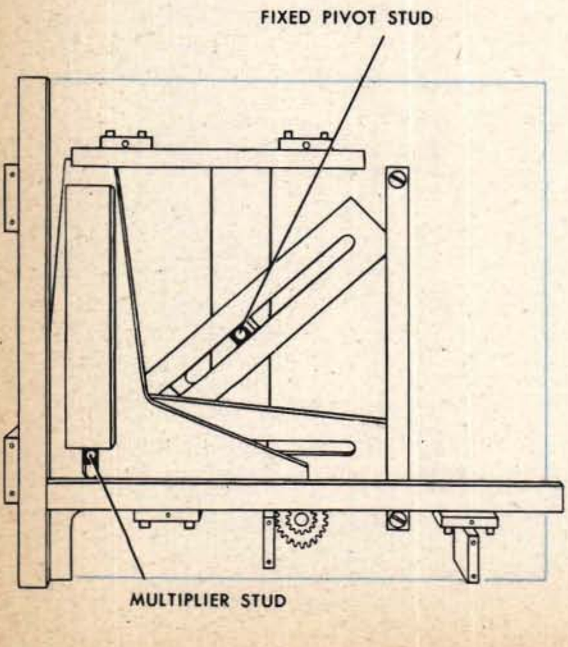


Shake each rack to check lost motion between the rack and its rail. If the lost motion exceeds the allowable limits given on the assembly drawing, adjust the upper roller studs.



Check for lost motion between the input and output racks by holding the output rack; then position the fixed-arm input rack at different points along its travel and shake the pivot-arm input rack. Excessive lost motion here may be caused by worn slide blocks or rack slots. The unit must be disassembled and the worn parts replaced.

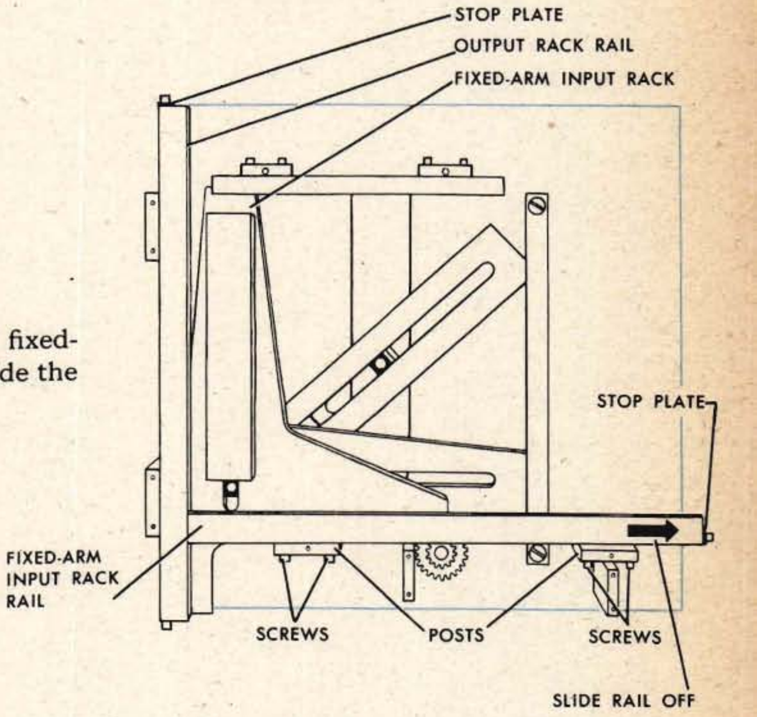
Slipping



Slipping may be caused by broken pivot studs. Check for a sheared pivot stud by placing one input rack at one end of its travel; then move the other input rack through its travel. Carefully observe the output rack to see whether it moves smoothly. If it does not, either the fixed pivot stud or the multiplier stud in the slide has been sheared or loosened. Repair requires disassembly of the unit.

Disassembling the unit

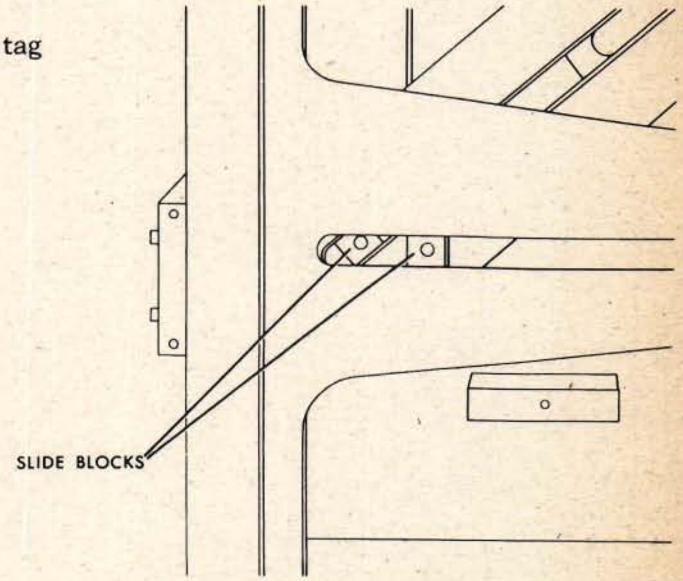
1 Remove the two stop plates. Remove the screw at the bottom of the output rack rail.

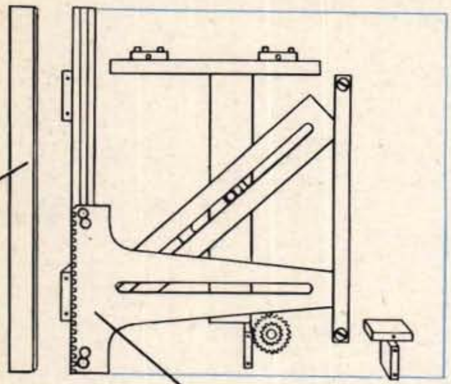


2 Take out the screws holding the fixed-arm input rack rail to the posts. Slide the rail off the rollers.

3 Lift off the fixed-arm input rack.

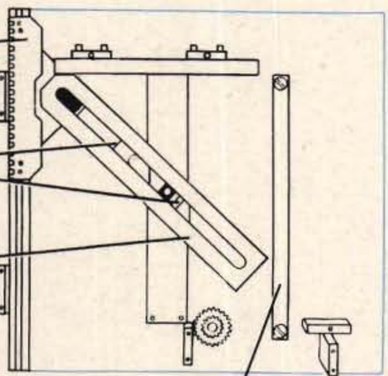
4 Lift out the two slide blocks and tag them.



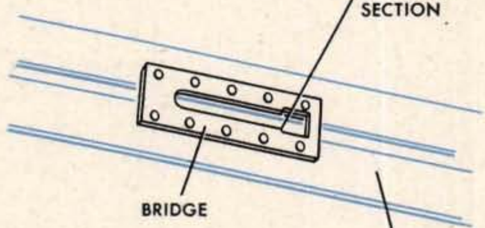


5 Remove the output rack rail.

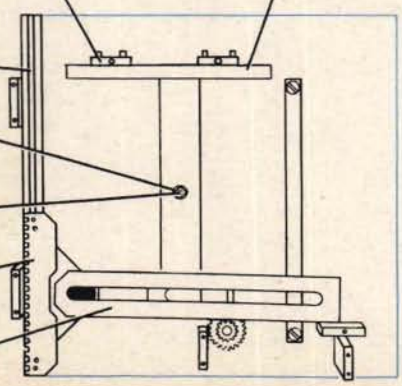
6 Take off the output rack.



7 Move the pivot-arm input rack so that the slide block is in the cutaway section of the bridge. Raise the arm off the block.



UNDERSIDE OF PIVOT ARM



8 Remove the snap ring and spacer from the fixed pivot stud.

9 Remove the slide block from the fixed pivot stud.

10 Remove the fixed-arm input rack guide.

11 Remove the post indicated in the illustration.

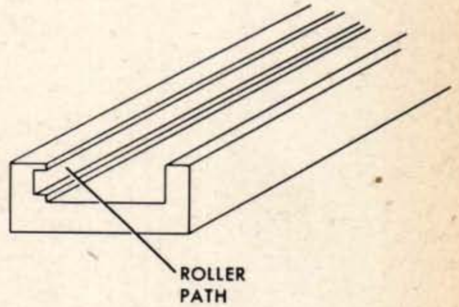
12 Run the pivot-arm input rack up, out of the rail.

13 Remove the plate holding the fixed pivot stud.

Repairing the parts

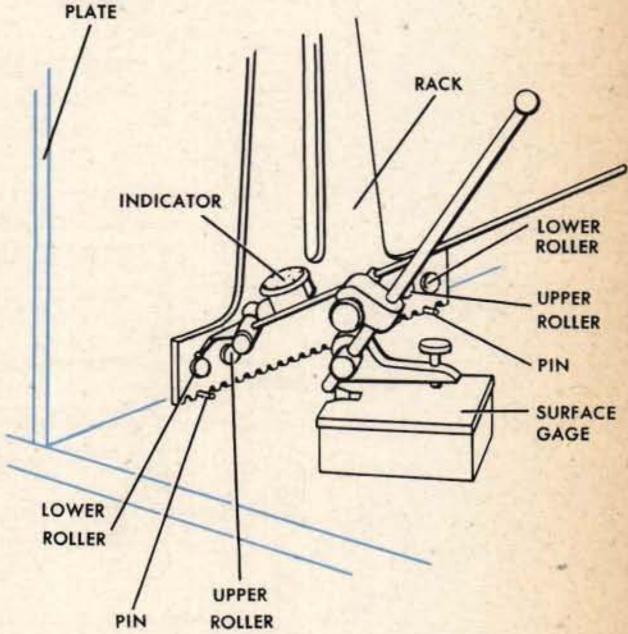
Repairing the input and output rails

Clean the roller paths with an approved solvent, and examine them carefully for embedded foreign matter. Polish any rough or high spots by stroking the roller paths with a square steel bar wrapped in crocus cloth. Run the rack in the rail frequently until a good fit is obtained. Then clean and lubricate the parts thoroughly.



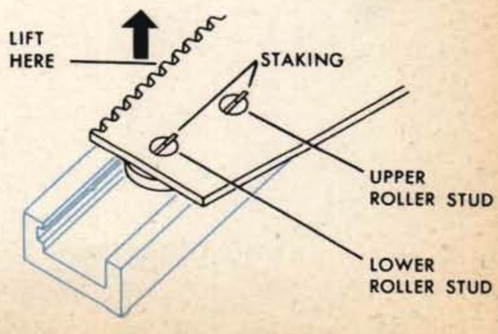
Adjusting the rollers

The lower rollers establish the pitch line of the rack in relation to its meshing gear. These rollers affect the alignment of the rack slots as well as the mesh of the rack and the gear. Remove the rack and mount it against an angle plate on a surface plate. Support the rack under the teeth, using two identical pins between 0.070 inch and 0.075 inch in diameter. Place a pin at each end of the rack.



With a surface gage and a dial indicator, measure the height of the lower rollers. The heights of these rollers must agree with the assembly drawing and be within 0.0002 inch of each other.

The upper rollers control the play between the rack and the rail. If the play exceeds 0.0005 inch, turn the roller studs with a screw driver. A strip of feeler gage material (0.001 inch) can be used to check the clearance between the roller and the roller path. After positioning the rollers, stake a small amount of metal into the screw-driver slots of the stud heads. The rollers should be free enough in the rail for the rack to drop back of its own weight if it is raised slightly with one finger.



For an explanation of removing and replacing a riveted stud, see pages 76-79.

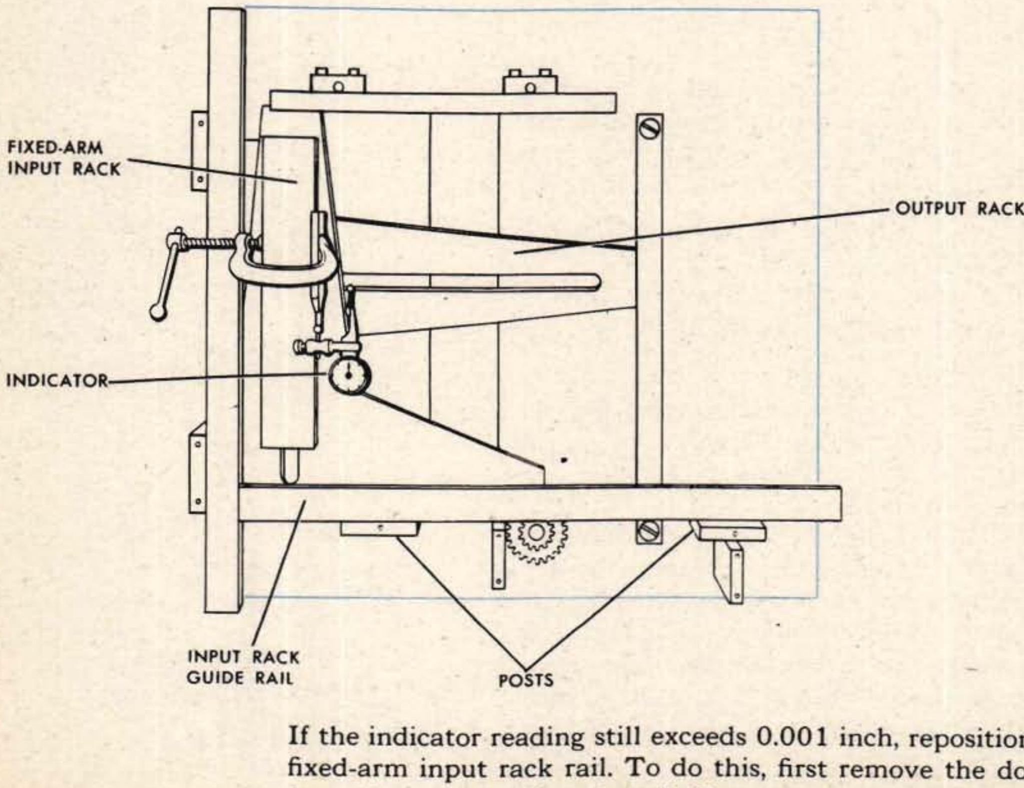
Squaring the racks

The slots in the fixed-arm input and the output racks must be at right angles to each other.

First reassemble on the plate the fixed-arm input and the output racks, their rails, and guides. Do not install the slide blocks and the pivot-arm input rack.

Wedge the output rack. Then mount a dial indicator firmly on the input rack with the point of the indicator on one face of the slot in the output rack. Move the input rack through its full travel. Observe the reading of the dial as the indicator point moves along the face of the output rack slot.

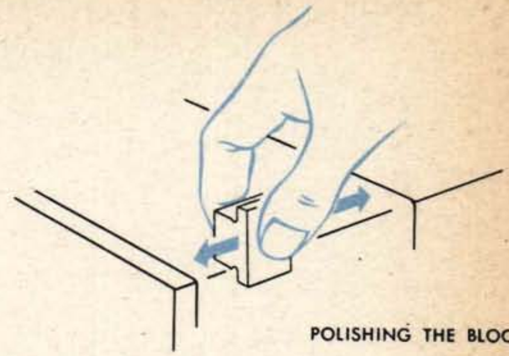
If the indicator reading exceeds 0.001 inch, check the setting of the lower rollers in the output rack as explained on page 209. It is advisable to check the lower rollers of the fixed-arm input rack at the same time. Replace the two racks and repeat the check for squareness.



If the indicator reading still exceeds 0.001 inch, reposition the fixed-arm input rack rail. To do this, first remove the dowels from the posts holding the rail. Then adjust the position of the posts until a true reading is obtained. Tighten the post screws. Use oversize dowels to redowel the posts.

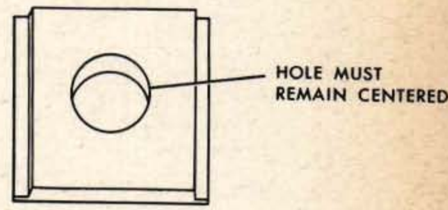
Fitting new slide blocks in the racks

Smooth any burred or rough edge of the block with a fine oilstone. Remove any extremely sharp edges, but leave them square. It is very important not to round or chamfer the edges.



POLISHING THE BLOCK

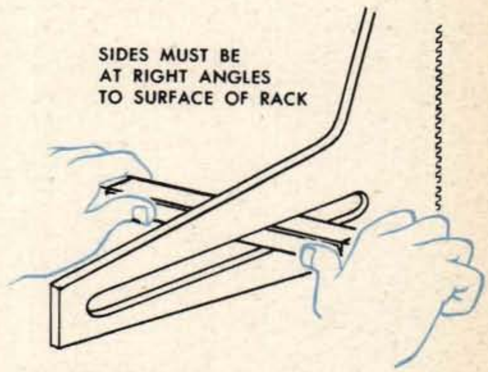
To reduce the width of the block, polish the sides on a piece of crocus cloth placed on a flat surface. Remove equal amounts from both sides so that the hole in the block remains centered. Use long, even strokes while holding the block square. Check it occasionally with a micrometer to be sure that the sides are parallel.



SIDES MUST BE PARALLEL

Polish the block to a close fit in the widest part of the slot. Then polish the rest of the slot to fit the block, using crocus cloth wrapped once around a square steel bar. Keep the sides of the slot parallel to each other and at right angles to both the flat surface of the rack and the pitch line of the rack teeth.

Before trying the block in the slot, wash with an approved solvent, dry and lubricate both parts thoroughly. The fit is right when the block can be moved the full length of the slot. Move the block back and forth by hand until it travels the full length smoothly.

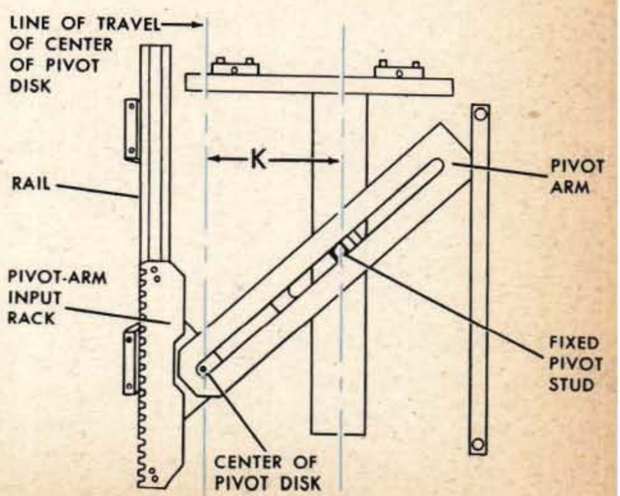


POLISHING THE SLOT

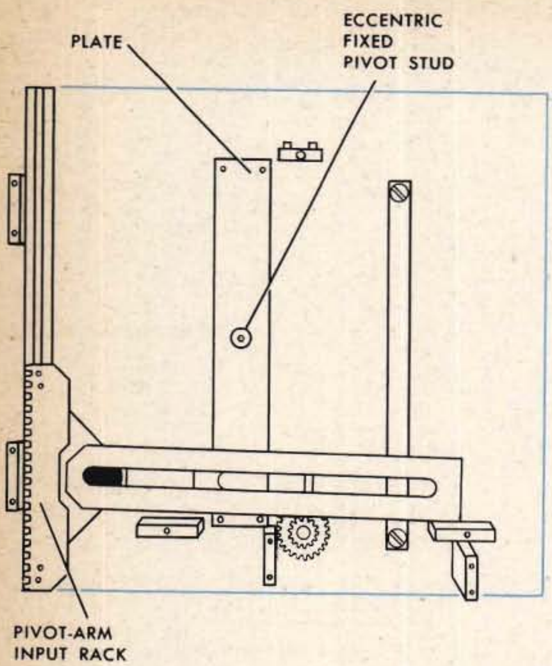
Replacing the pivot studs

For instructions on removing and riveting the multiplier stud in the fixed-arm input rack slide block and the fixed pivot stud in the plate, refer to pages 76-79.

The distance between the center of the fixed pivot stud and the line of travel of the pivot disk must be correct in order to obtain the correct output from the multiplier. This distance, which represents the constant, K, in the mathematical explanation of the multiplier, is designated on the assembly drawing. Turn the fixed pivot stud, which is eccentric, until the exact measurement is obtained; then "stake" the plate in order to hold the stud in position.

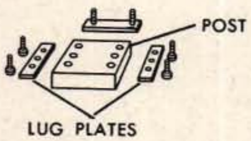


Reassembling the unit

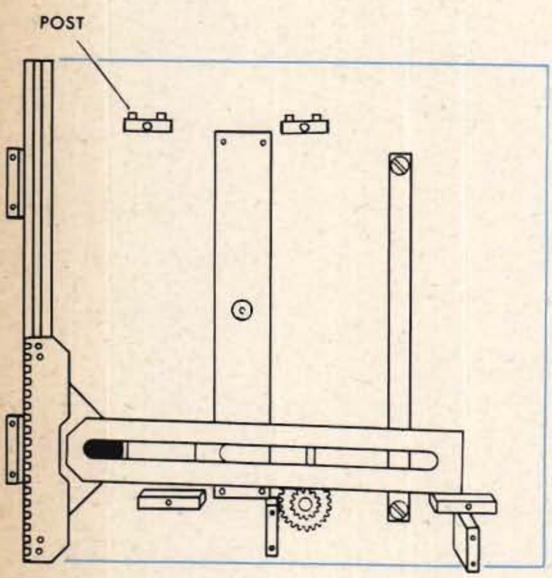


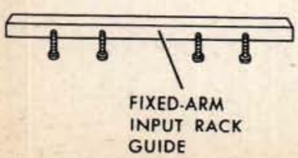
1 Mount the plate holding the eccentric fixed pivot stud. Tighten the four screws.

2 Mount the pivot-arm input rack by sliding it down in its rail.

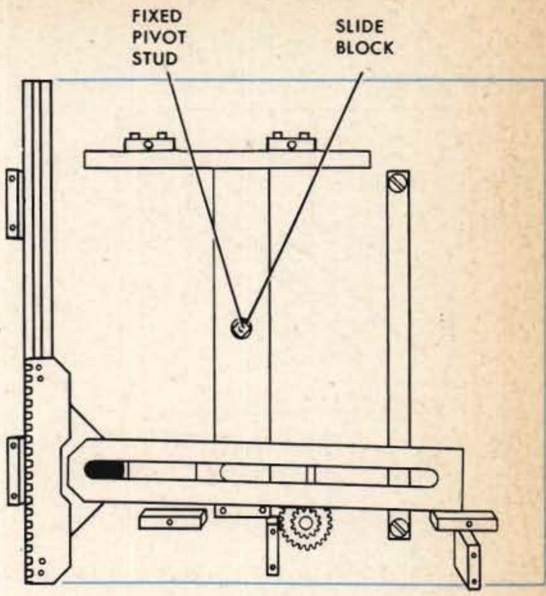


3 Mount the post and secure it to the base plate.





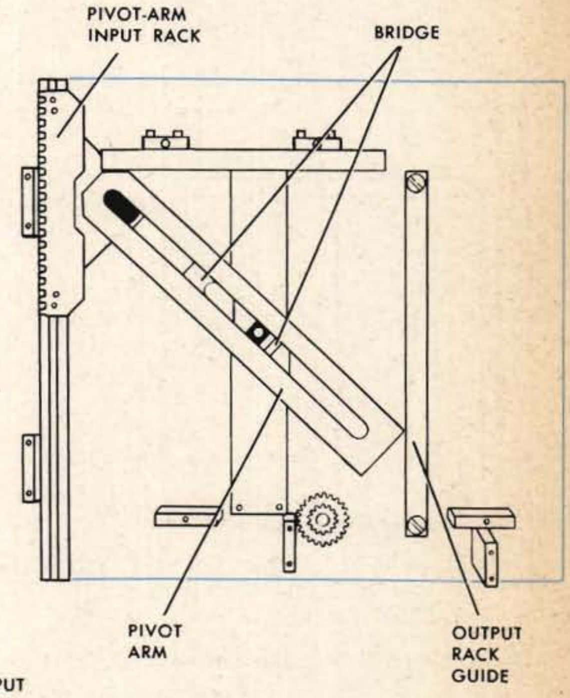
4 Mount the fixed-arm input rack guide so that the side which is nearer the slot will be toward the base plate.



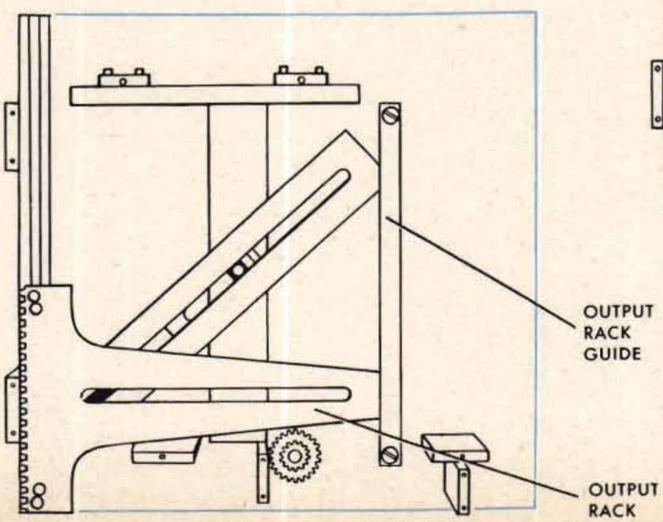
5 Place the slide block (flanges up) on the fixed pivot stud.

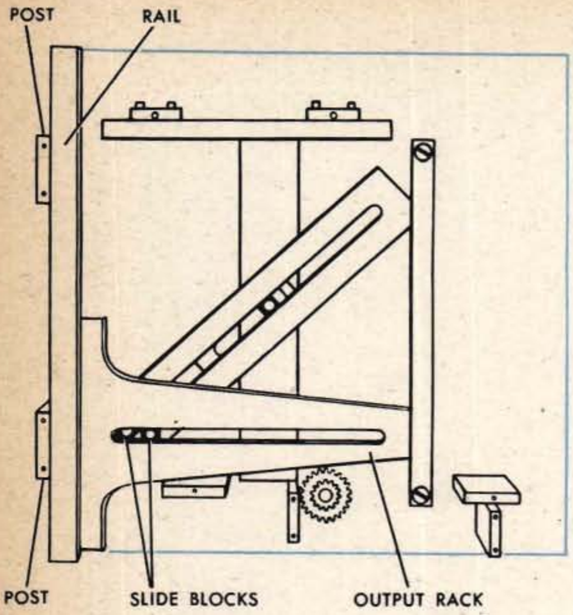
6 Put the spacer and snap ring on the fixed pivot stud.

7 Move the pivot arm to align the cutaway section of the bridge with the slide block on the fixed pivot stud. Then carefully move the pivot arm until the slide block rides into the bridge slot and the end of the pivot arm goes under the output rack guide.



8 Place the end of the output rack in its guide.

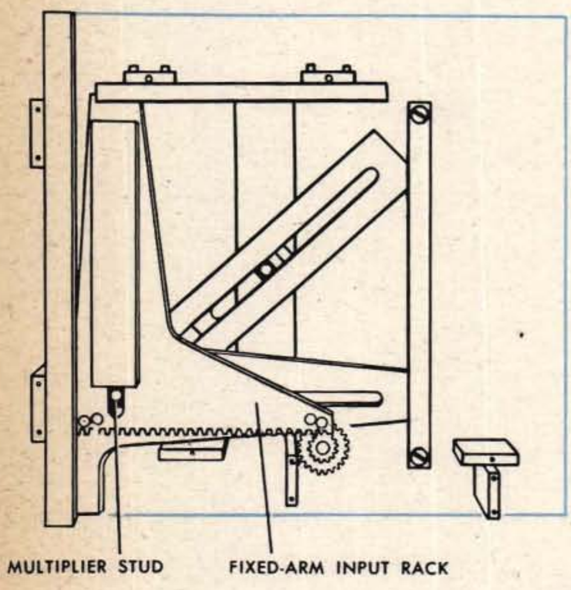




9 Slide the rail on the output rack rollers. Fasten the rail to the posts.

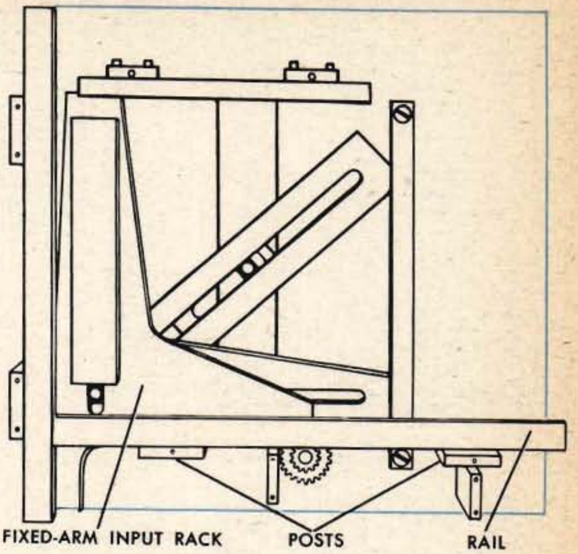
10 Place the slide blocks in the output rack slot and in the pivot arm slot.

11 Align the holes in the two slide blocks.



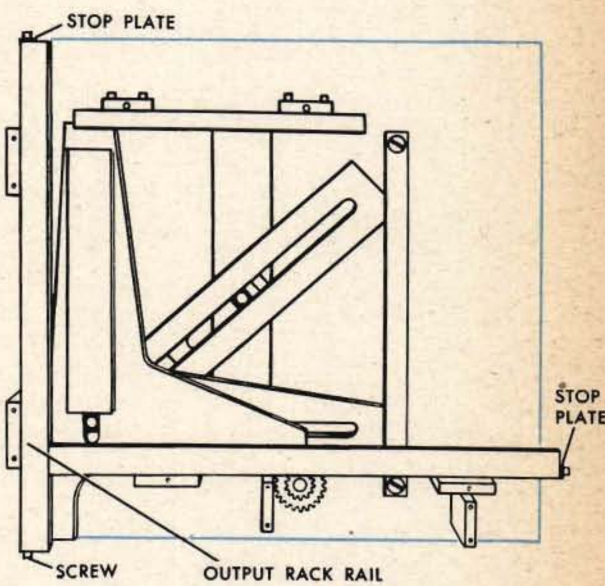
12 Set the end of the fixed-arm input rack in its guide and put the multiplier stud through the holes in the two slide blocks.

13 Slide the rail on the fixed-arm input rack rollers. Fasten the rail to the posts.



14 Fasten the rail of the output rack to the bottom stop plate.

15 Mount the two stop plates.



Bench checking the unit

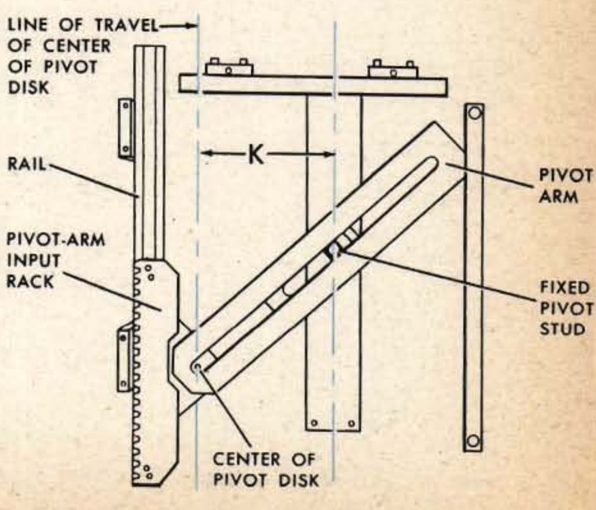
1 Check the unit against the assembly drawings.

2 All the gear meshes must be free and have a minimum of lost motion.

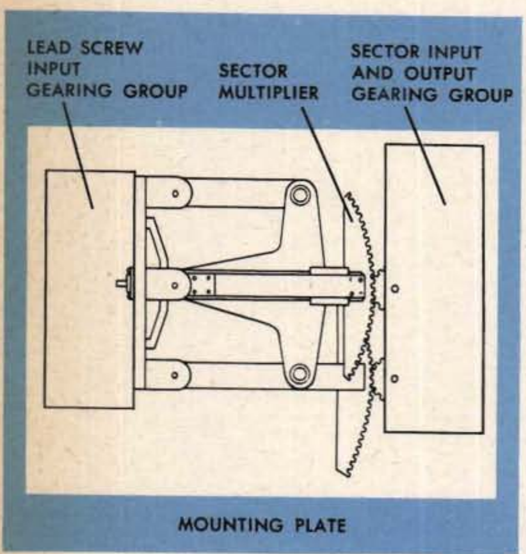
3 The racks must move freely through their full travel.

4 The eccentric roller studs in the racks and the eccentric fixed pivot stud must be tight and staked.

5 The distance, *K*, between the center of the fixed pivot stud and the line described by the center of the pivot disk as the pivot-arm input rack is moved through its travel must agree with the distance indicated on the assembly drawing.

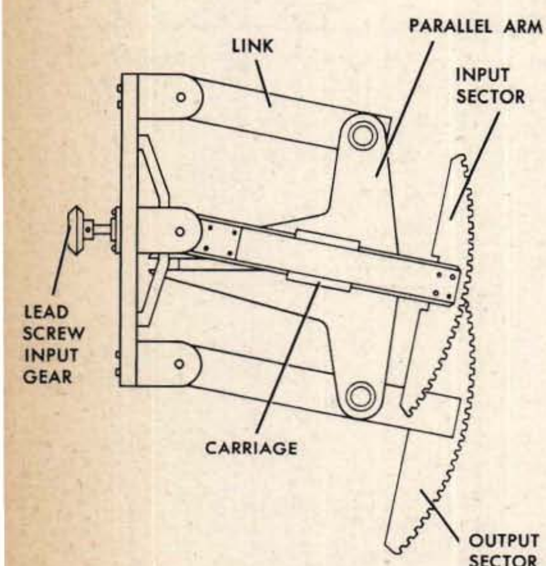


THE SECTOR TYPE MULTIPLIER



Sector multipliers are usually mounted in groups. They are mounted side by side, and the whole group forms one assembly. In a multiplier group, all the lead-screw input gearing makes up one gearing group at one end of the assembly. At the opposite end, all the sector input and output gearing makes up another gearing group.

In order to remove one multiplier, it is usually necessary to remove the entire sector gearing group connecting with all the multipliers. Before this gearing group is removed, however, the trouble must be exactly located in one multiplier. If the unit must be removed for repair, consult the instrument OP for instructions.



Typical symptoms

If a test analysis and unit check tests have indicated that a sector multiplier is not operating normally, look for the following typical symptoms:

LEAD SCREW INPUT—JAMMING: The lead-screw input gear cannot be turned by hand.

LEAD SCREW INPUT—STICKING: The lead-screw input gear resists turning past a certain point or points, or turns sluggishly.

LEAD SCREW INPUT—EXCESSIVE LOST MOTION: There is too great a lag between the turning of the gear and the movement of the traveling nut and carriage.

LEAD SCREW INPUT—SLIPPING: Turning the lead-screw input gear moves the traveling nut and carriage only intermittently.

SECTORS—JAMMING: One or both sectors cannot be moved by hand.

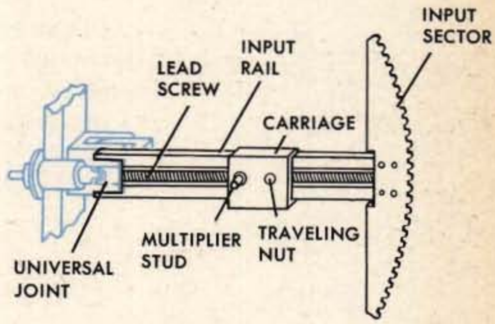
SECTORS—STICKING: One or both sectors resist moving past a certain point or points, or move sluggishly.

SECTORS—EXCESSIVE LOST MOTION: When one sector is held stationary and the other is shaken, there is too much play between them.

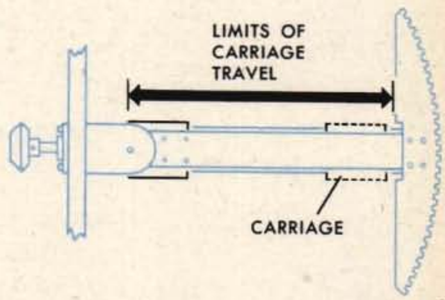
SECTORS—SLIPPING: Moving either input does not move the output.

Locating the cause

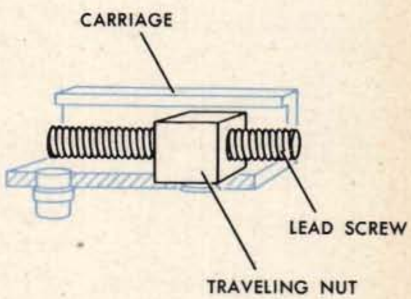
Lead screw input: jamming or sticking



A lead screw may jam or stick because the traveling nut has run too far in or out; or because of dirty or defective threads in the nut or on the screw; or because of a bent screw. If any of these parts needs to be replaced, the unit should be removed from the instrument for disassembly.



If the traveling nut has run beyond its normal travel and jammed against adjoining parts, it can usually be backed out of its position by hand. Try to move it by turning the lead-screw input gear. After it comes free, run the traveling nut through its full travel to be sure that the nut and screw threads are undamaged. This type of jamming is caused by an incorrect limit-stop setting. Directions for resetting the limit stop are given in the instrument manual.



If the traveling nut sticks or binds at only one point, the lead-screw threads are probably the cause. Examine them closely at this point. Remove any dirt or embedded particles. Then lubricate the lead screw and run the carriage back and forth by turning the input gear until the nut travels smoothly. A badly damaged or bent lead screw should be replaced.

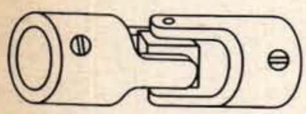
If the traveling nut sticks or binds along its entire travel, the cause of the trouble may be dirty or damaged threads in the nut. The nut should be removed for repair.

NOTE: Check lead screw and traveling nut for lost motion after correcting any jamming or sticking.

Lead screw input: excessive lost motion

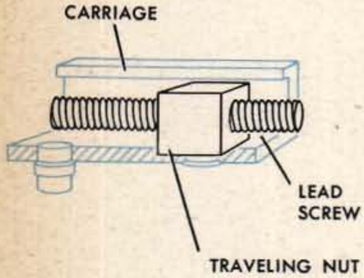
The assembly drawing specifies the allowable maximum of lost motion between the lead-screw input gear and the parallel arm. Excessive lost motion may be caused by worn threads on the lead screw or in the traveling nut, or by worn parts in the universal joint.

THE UNIVERSAL JOINT



Inspect these parts for wear, and replace any that are worn enough to cause excessive lost motion. To remove the lead screw or universal joint, or to tighten or replace a nut, the multiplier should be removed from the instrument.

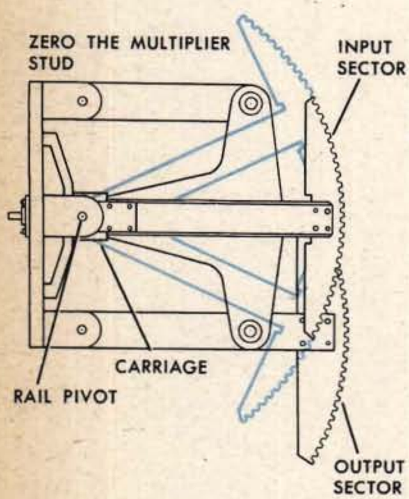
Lead screw input: slipping



Slipping may be caused by sheared pins in the lead screw, the input shaft, or the universal joint, or by stripped threads on the lead screw or nut. Repairing any of these parts requires removal and disassembly of the unit.

Sectors: jamming or sticking

Move the input sector through its full travel to check the smoothness of operation. If it jams or sticks, the cause of the trouble is in either the input or the output sector.



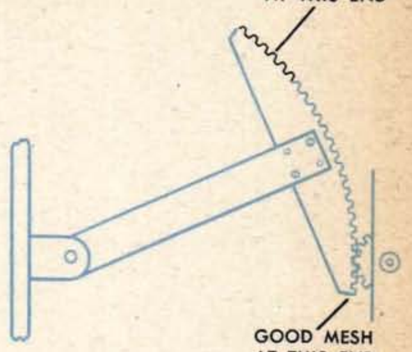
Turn the lead screw until the multiplier stud is over the rail pivot to obtain zero movement of the output sector. Then move the input sector through its full travel. If the input sector binds or jams while the stud is in this position, the trouble may be caused by a damaged rail pivot, damaged gear teeth on the input sector, or the slide block frozen on the stud.

If the input sector travels smoothly when the output sector is centered, and jerkily when the output sector is moved, the cause of the trouble may be the gear teeth on the output sector, the pivot studs, or the slide block or slot in the parallel arm.

Repairing any of the parts requires removal and disassembly of the unit.

Sectors: slipping

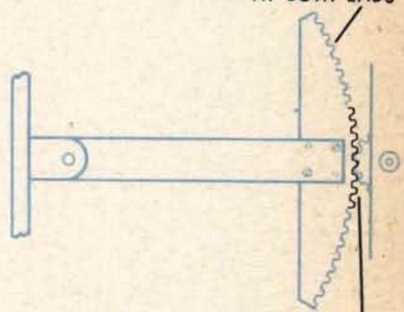
If moving either input does not move the output sector, the trouble is probably caused by a missing or sheared stud. If turning the lead-screw input gear does not turn the output sector, the trouble is probably caused by sheared or missing pins in the universal joint. Replacing any of these parts requires removal and disassembly of the unit.



Sectors: excessive lost motion between them

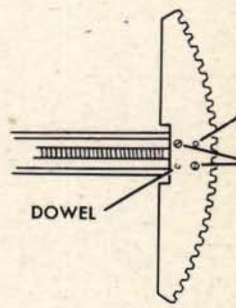
Excessive lost motion between the sectors may be caused by a loose, worn, or bent multiplier stud, a worn slide block or slot in the parallel arm, or a worn pivot stud.

A worn stud, slide block, parallel arm slot, or pivot stud cannot be repaired. The worn parts should be replaced.



Sectors: excessive lost motion at the gear teeth

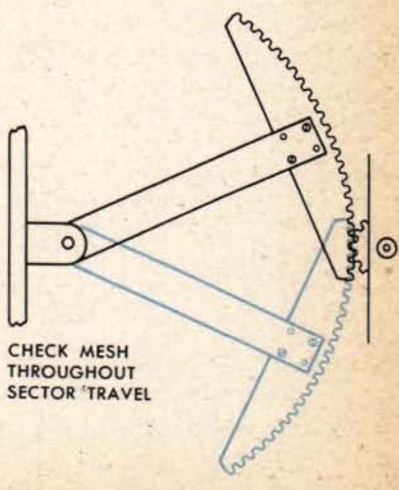
A sector which has excessive lost motion at the gear teeth, either at one end or along its entire travel, can often be repositioned on its arm. A sector which has excessive lost motion only at the center gear teeth and correct lost motion at both ends should be replaced. Repositioning or replacing a sector does not necessarily require removal and disassembly of the unit.



Adjusting or replacing a sector

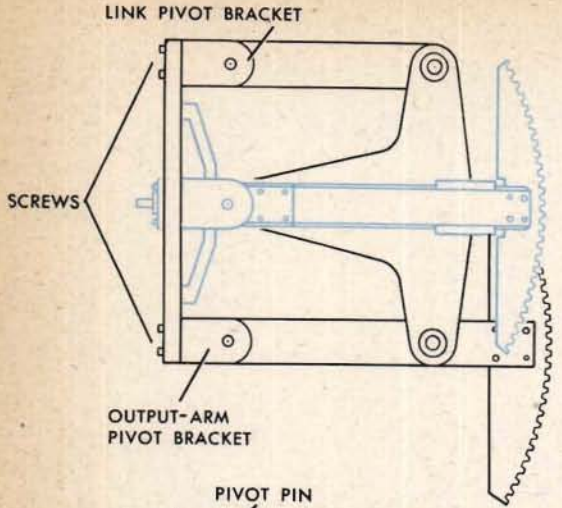
Move the sector back and forth to see whether it can be removed without disturbing the connected gearing group. If necessary, remove the gearing group. To remove the sector from the arm, take out the two screws and tap the sector until it comes free from the dowels, which should remain on the arm.

To reposition a sector, tap out the dowels and replace it on the arm, tightening the screws only enough to hold the sector while it is repositioned. Replace the gearing group and move the sector against the screws until the gear teeth mesh correctly along its entire travel. Then tighten the screws. Protect nearby mechanisms with tissue and redowel with oversize dowels. For a detailed explanation of doweling see pages 74-75.

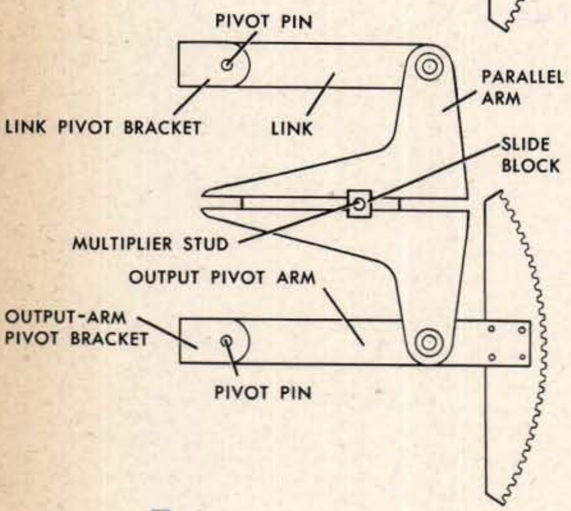


CAUTION: This procedure should be followed only in an emergency. Preferably, the sector and arm should be removed for redoweling after the gear mesh has been adjusted.

Disassembling the unit

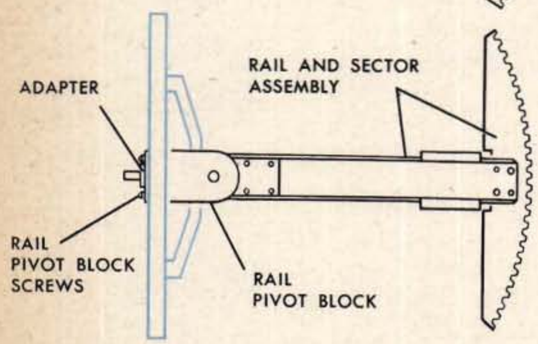


1 Remove the screws holding the link pivot bracket and the output-arm pivot bracket to the base plate.



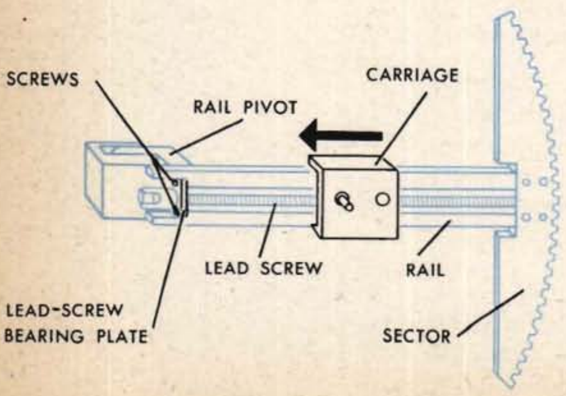
2 Slide out the assembly consisting of the two pivot brackets, the output arm, the parallel arm, and the link. Remove the slide block from the multiplier stud.

Do not disassemble this group unless the pivot pins or the parallel arm require replacement.



3 Remove the lead-screw input adapter from the base plate.

4 Remove the screws that hold the rail pivot block to the base plate and lift off the rail and sector assembly.



5 Remove the two screws holding the lead-screw bearing plate and turn the lead screw out of the traveling nut.

6 Slide the carriage off the rail.

7 Do not remove the sector from the rail unless the sector must be repositioned or replaced.

8 Do not remove the rail pivot unless it must be replaced.

Repairing the parts

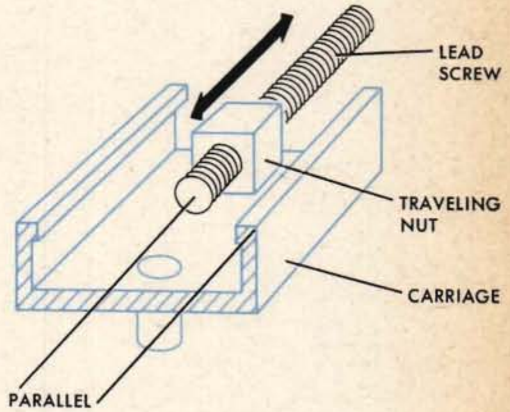
Fitting a new lead screw

Inspect the new lead screw for nicks or dirt in the threads. Make sure that the threads are not bent or turned at the ends of the screw. Remove dirt or foreign matter, and smooth out small nicks. Make sure that the traveling nut threads are clean and undamaged.

Apply lubricant to both parts and start the screw into the nut slowly and carefully. Run it back and forth in the nut until it moves smoothly throughout its travel.

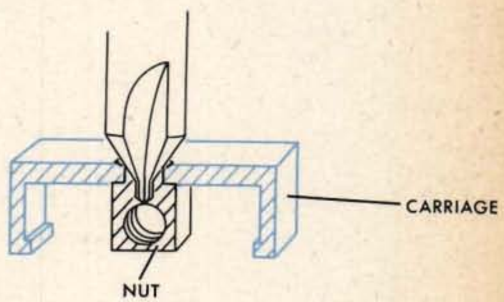
Remove the lead screw from the nut and fit it to the bearing plate and the universal coupling end. Pin the coupling end to the lead screw.

Finally, wash all the parts thoroughly in a suitable solvent and relubricate them.

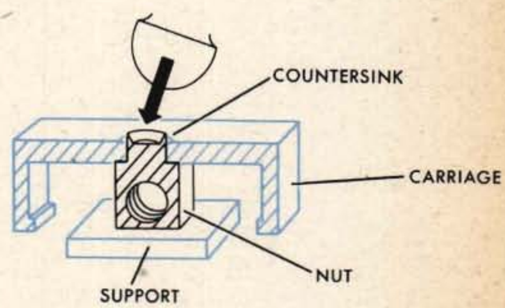


Replacing a traveling nut or multiplier stud

Remove the riveted portion with a center drill, and support the carriage to prevent distortion while driving out the old part with a punch and a light hammer.



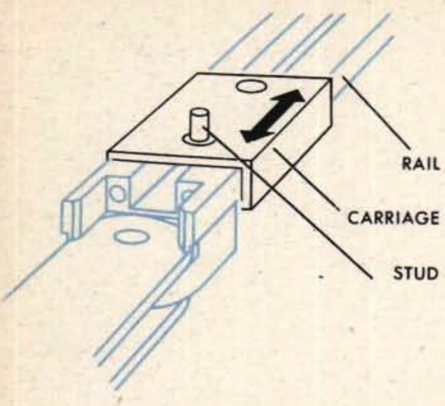
TO REPLACE A NUT, first fit the new nut to the screw. Then remove the nut and fit it in the carriage hole. Finally, support the head of the nut and tap with a ball peen hammer until the lip is brought down evenly into the countersink in the carriage. Be very careful not to distort the threaded hole by hammering too hard. Position the nut so that the lead screw will be parallel to the side of the carriage.



TO REPLACE A STUD, first fit the stud to the slide block. Then insert it in the hole in the carriage. Support the carriage and peen over the end of the stud.

For a detailed explanation of removing and replacing parts which are riveted in this way, see pages 77-79.

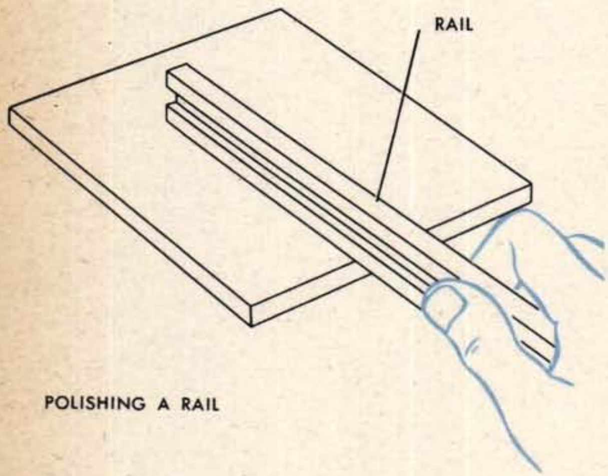
Fitting a new carriage to a rail



First fit and rivet a new stud and a new nut to the carriage. Then lubricate both the carriage and the rail.

With the lead screw removed, carefully start the carriage on the rail. If it does not start easily, do not force it, because forcing it will raise a burr.

In fitting a new carriage, polish only the sliding surfaces of the rail—never of the carriage. Polish the rail by rubbing it lightly and evenly against a very fine abrasive cloth or paper placed on a smooth, flat surface. Try the carriage on the rail frequently in order to avoid polishing the sliding surfaces down too much. The operation is complete when the carriage moves freely over the full length of the rail.



POLISHING A RAIL

Lubricate the rail and run the carriage back and forth by hand until it moves smoothly from one end to the other with a minimum of play.

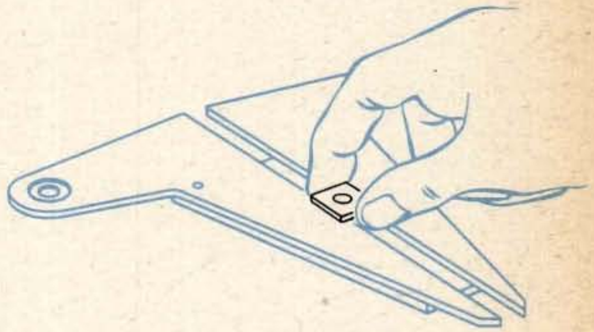
Fitting a new slide block

POLISHING THE BLOCK

Use a fine oilstone to smooth burred or rough edges of the block. Remove any extremely sharp edges, but leave them square. It is very important not to round or chamfer the edges.

To reduce the width of the block, polish the sides on a piece of crocus cloth placed on a flat surface. Be sure to remove equal amounts from both sides so that the hole remains perfectly centered. Use long, even strokes while holding the block square. Measure it occasionally with a micrometer to be certain that the sides are parallel.

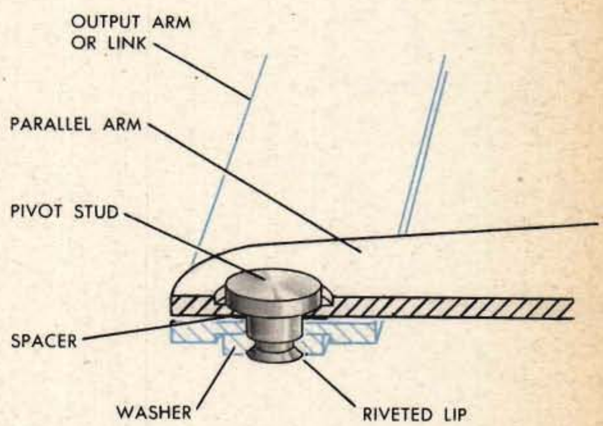
Polish the block until it is a close fit in the widest part of the slot in the parallel arm. Polish the rest of the slot to fit the block, using crocus cloth wrapped once around a steel bar. Be sure to keep the sides of the slot parallel and flat.



Before trying the block in the slot, thoroughly wash, dry, and lubricate them both. The fit is correct when the block can be moved the full length of the slot. Move the block back and forth by hand until it travels smoothly from one end to the other. Finally, wash the block and the slot again, and lubricate the slot.

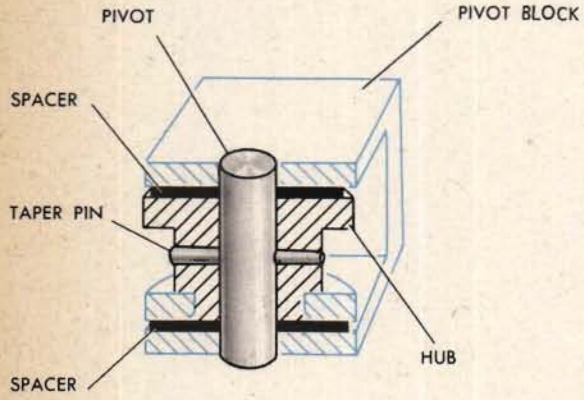
Replacing a parallel arm pivot stud

First remove the riveted portion with a center drill. Then support the arm to prevent distortion while driving out the old stud with a punch and a light hammer. Fit the new stud in the hole in the parallel arm and in the link or output arm. If necessary, ream one or both holes for a snug fit. Place the spacer between the two parts, insert the stud, and put the washer over the end of the stud. Press the washer firmly against the stud shoulder and swing the parts or rotate the stud to see whether the parts are free to turn. If the parts bind, file the spacer until they move freely. Finally, support the head of the stud and tap with a ball peen hammer to bring the lip down evenly into the countersink in the washer.



For a detailed explanation of removing and replacing parts which are riveted in this way, see pages 77-79.

Replacing an arm or link pivot

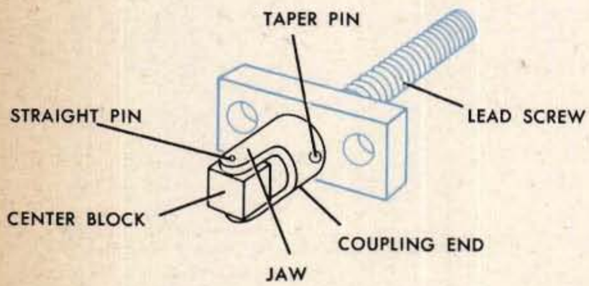


First tap out the taper pin from the small end and then drive out the pivot. Inspect the holes for wear, and if they are worn, replace the pivot block.

The new pivot must be fitted to the hole before the parts are assembled. A hard push-fit is required in a hub or rail support, and a light push-fit with no lost motion in a pivot block. If necessary, ream the holes to fit the pivot, or use a slightly oversize pivot if the standard size is too loose.

Assemble the parts with the two original spacers in place and insert the pivot. Drill a taper pin hole and seat the pin. Finally, remember to stake the large end of the pin.

Replacing a block in a universal joint



First remove the lead screw from the rail. To release the block, tap out the straight pin that fastens it to the coupling end. The new block should fit freely between the jaws without play or lost motion.

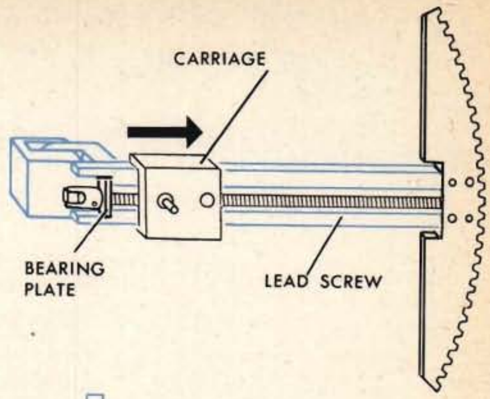
If the jaws are worn, replace the coupling end. Polish the inner surfaces of the jaws to assure smooth operation. If the block is slightly large, polish the faces until it fits between the jaws.

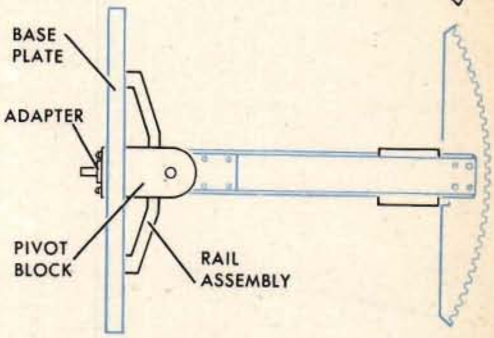
Polish the opposite faces equally on a piece of crocus cloth placed on a smooth, flat surface. When the block fits correctly, position it between the jaws and tap in the straight pin. To make sure that the pin is retained in place, stake some metal over the ends from both jaws of the coupling end. After staking, make sure that the block is still free to turn.

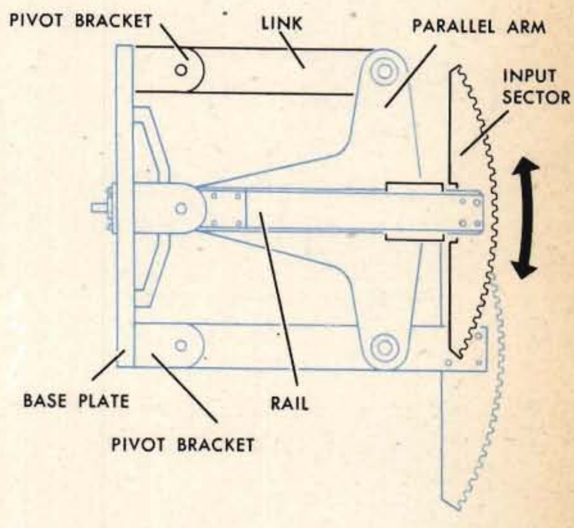
Reassembling the unit

Wash and dry all the parts before starting to reassemble the unit, and lubricate each part before replacing it.

1 Slide the carriage onto the rail.
2 Hold the carriage near the rail support and turn the lead screw through the traveling nut.
3 Fasten the bearing plate to the rail.
4 Turn the lead screw to move the carriage through its travel to check for freedom of movement.
5 Mount the rail assembly on the base plate and fasten the pivot block.
6 Replace the adapter shaft assembly. Check the alignment of the coupling and the screw.
7 Replace the slide block on the multiplier stud.
8 On the base plate, position the large assembly composed of the parallel arm, the rail, the input sector, and the link assemblies.
9 Position the slide block in the parallel arm slot.
10 Fasten the two pivot brackets to the base plate.
11 Turn the lead screw to move the carriage through its full travel to check for smoothness.
12 Move the input sector through its full travel to check for smoothness.





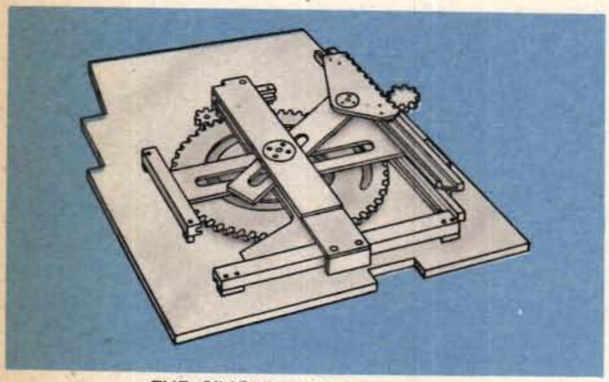


Bench checking the unit

1 Check the assembly of the unit against the assembly drawing.
2 The lead-screw input should be free when the input sector is at either end of its travel.
3 Lost motion at the universal joint should not exceed the allowable maximum specified on the assembly drawing.
4 Move the carriage until the multiplier stud is directly over the rail pivot. At this zero position, moving the input sector should not move the output sector. Mark this carriage position on the input arm with a scriber.
5 Move the carriage one inch from the marked zero position. When the input sector is held stationary, lost motion measured at the output sector teeth should not exceed the amount shown on the assembly drawings.

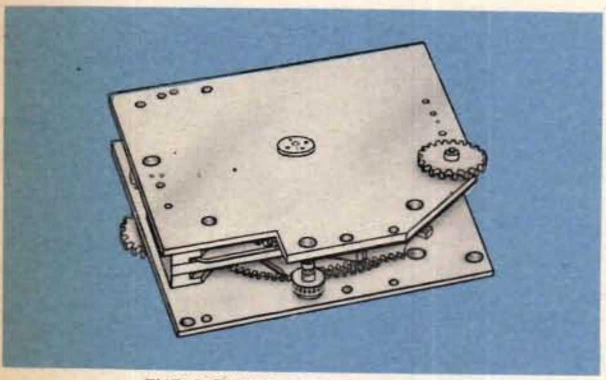
CAM TYPE MULTIPLIERS

Single and double cam multipliers are similar in both construction and operation. The main mechanical difference between them is that in the single cam multiplier the pivot arm is positioned by a rack, but in the double cam multiplier it is positioned by a cam. Except for this difference, checking for symptoms of mechanical trouble is the same for both units, and the repair procedures are nearly identical. If a cam multiplier must be removed for repair, consult the instrument OP for instructions.



THE SINGLE CAM MULTIPLIER

A single cam multiplier may be mounted either on a separate base plate or on a plate with gearing groups or other units. The inputs position the cam and the pivot-arm rack. The output is taken from the fixed-arm rack.



THE DOUBLE CAM MULTIPLIER

A double cam multiplier is usually mounted on a separate base plate. All the working parts are mounted between two plates and, consequently, can be seen only from the sides. The inputs position the cams while the output is taken from the output rack. In certain applications of this unit, an intermediate output is taken from the cam follower slide.

Usually one spiral cam and one square cam are used in the double cam multiplier, but in some cases both cams are of the spiral type. A square cam has a continuous groove which allows it to make any number of turns in either direction. A spiral cam turns only until the follower reaches either end of the groove.

A SPIRAL CAM

A SQUARE CAM

Typical symptoms

If a test analysis and a unit check test indicate that a cam type multiplier is not operating normally, look for one or more of the following typical symptoms:

JAMMING: One or both inputs cannot be moved by hand.

STICKING: One or both inputs resist moving past a certain point or points, or move sluggishly.

EXCESSIVE LOST MOTION: There is too great a lag between the movement of an input and an output; or when the inputs are held and the output shaken, there is too much play between them.

SLIPPING: Moving the inputs does not move the output, or moves it only intermittently.

Locating the cause

Jamming: single cam unit

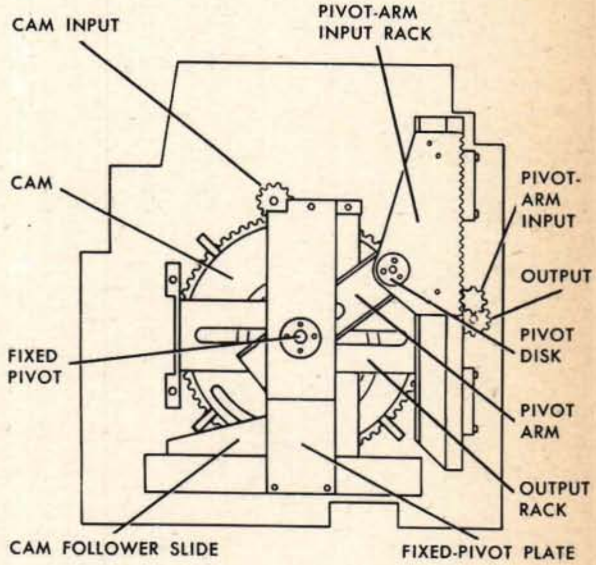
Try both inputs to determine whether one or both are jammed.

If neither input can be moved, the channel may be binding on the pivot arm or the slide block may be jammed in the cam follower slide.

If only the pivot-arm input is jammed, look for one of the following casualties: a slide block frozen on the multiplier stud, the carriage block binding in its slot or on the fixed pivot, a frozen pivot disk on the pivot-arm rack, the rollers of the pivot-arm rack jammed in the rail, or a damaged gear or rack tooth.

If only the cam input is jammed, the trouble may be due to dirt or chips in the cam groove, the slide block frozen in the output-rack slot, jamming of the cam follower slide rollers in the rail, or a damaged cam or input-gear tooth.

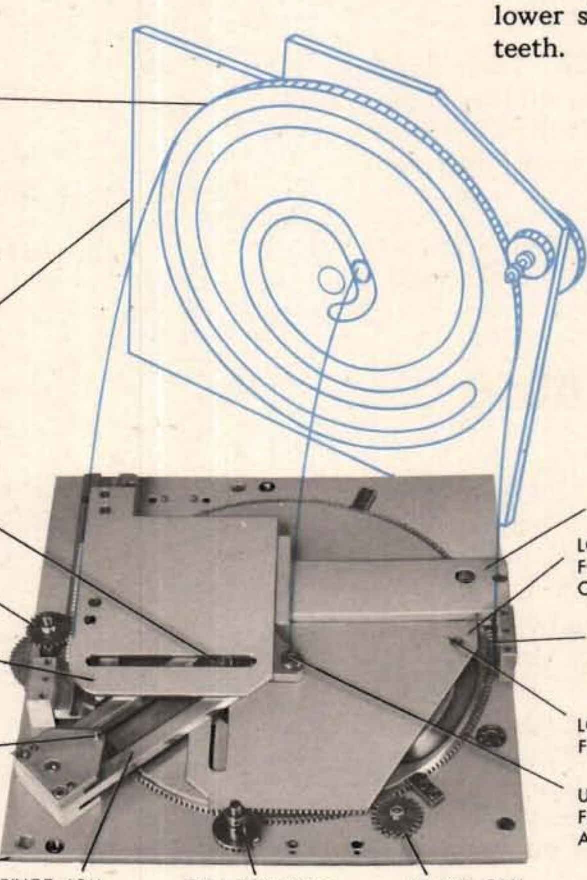
When the cam will turn only if the input rack is free to move, a jammed output rack is indicated. This may be caused by the rack rollers jamming in the rail, the slide block freezing in the cam follower slide, or damaged output rack teeth.



THE SINGLE CAM MULTIPLIER

Jamming: double cam unit

If neither of the cams will turn when both are in an active position (off zero), the slide block may be frozen in the pivot-arm slot or the output rack may be jammed. Jamming of the output rack may be caused by the rack rollers jamming in the rail, the slide block freezing in the cam follower slide, or damaged output-rack teeth.

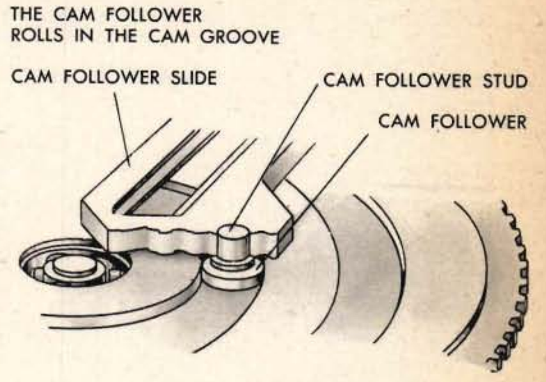


If only the lower cam is jammed, look for one of the following troubles: dirt or chips in the cam groove, the rollers of the cam follower slide jammed in the rail, the output-rack slide block frozen in its slot, or a damaged tooth on the cam or cam follower slide.

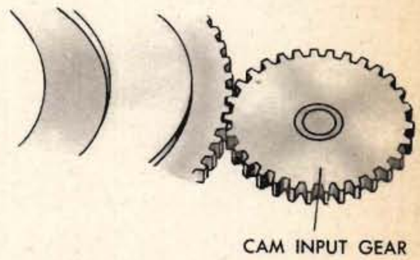
If the upper cam alone is jammed, the trouble may be caused by dirt or chips in the cam groove, or damaged cam teeth.

Cam: jamming

If a spiral cam is jammed at either end of its travel, try to move it out of the jammed position by hand. If the cam cannot be freed in this way, the cam-follower stud is probably bent, and the unit should be disassembled to repair it. This type of jamming is caused by an incorrect limit-stop adjustment. Instructions for readjustment are given in the instrument OP.

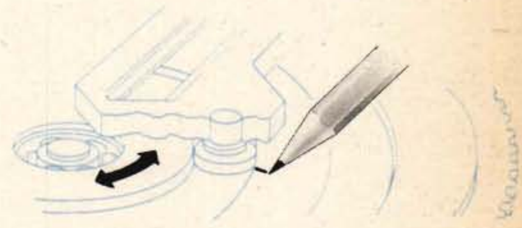


If either a square or spiral cam is jammed within its normal travel, the cause may be damaged teeth, a cam follower locked in its groove because of dirt or damage, or a bent follower stud. To repair the cam groove or any parts of the follower, the unit should be disassembled.



Cam: sticking

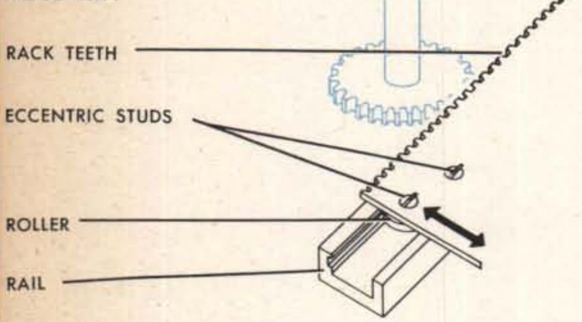
First inspect the teeth of the cam and its meshing gear at the point where these parts stick. Damaged or dirty teeth can sometimes be repaired in place.



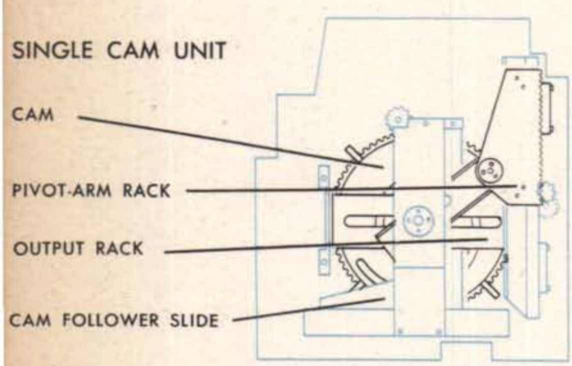
If the gears are not causing the cam to stick, turn it through its travel several times. As the cam moves, observe the position of the follower. If the cam sticks at the same place during each travel, mark the follower position on the face of the cam. Turn the cam until this part of the groove is visible. Wipe the groove clean with tissue and inspect it carefully for damage. Remove any foreign material or embedded particles.

Polish tight or rough spots with crocus cloth wrapped around a steel bar, being very careful not to enlarge the groove. Clean the groove thoroughly and lubricate it before turning the cam again.

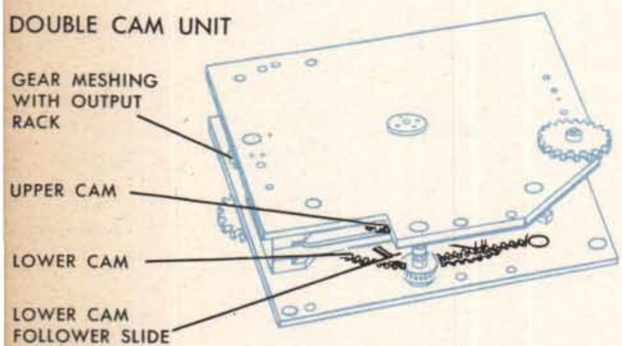
RACK AND RAIL ASSEMBLY



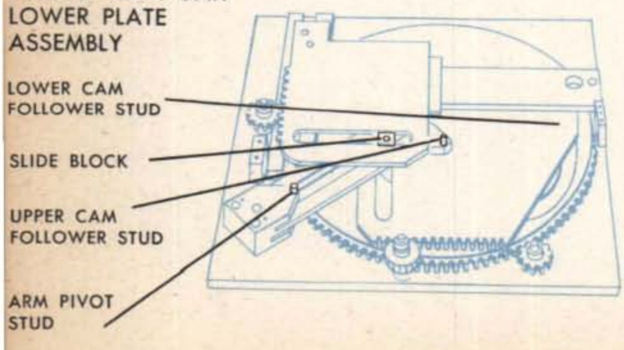
SINGLE CAM UNIT



DOUBLE CAM UNIT



DOUBLE CAM UNIT LOWER PLATE ASSEMBLY



Rack: sticking

If a rack sticks, inspect the rack and gear teeth for dirt or damage. Clean or repair them if necessary. A rack or gear with badly damaged teeth should be replaced.

Slight sticking can usually be eliminated by wiping the sliding surfaces clean, lubricating them, and running the sticking parts back and forth by hand. Do not disassemble the unit to make this repair unless it sticks enough to cause serious errors in the operation of the instrument.

Excessive lost motion

Shake each rack or slide to check for lost motion between the rollers and the rail. If the lost motion exceeds 0.001 inch, the piece should be removed in order to reposition the rollers.

To check for lost motion in the other parts, hold the output rack, position the spiral-cam follower at different points along its travel, and shake the input rack or cam. Excessive lost motion between these parts may be caused by a worn slide block or slot, or by a worn cam follower or groove. This lost motion can be reduced only by disassembling the unit and replacing the worn parts.

Slipping

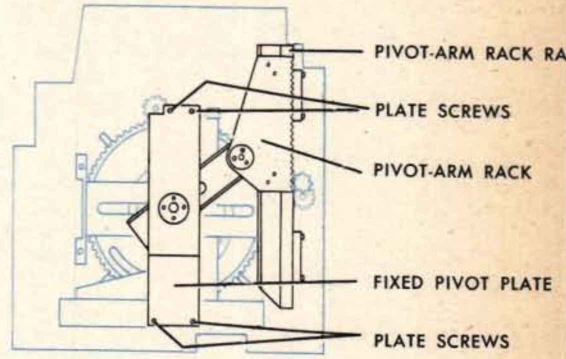
Slipping may be caused by a loose rack, stripped teeth, or by a broken pivot or follower stud. Observe the movement of the output rack while both inputs are moved through their travel. The output should move smoothly and evenly while the inputs are being moved. If it does not, the fixed pivot, the slide block pivot, or a cam follower stud may be loose or sheared. To repair or replace any of these parts, the unit should be disassembled.

Disassembling the single cam unit

1 Remove the four screws that secure the fixed pivot plate and the two screws that hold the pivot-arm rack rail.

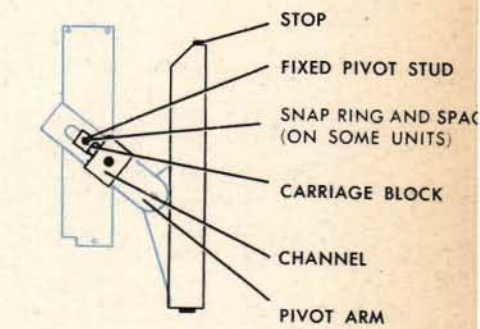
2 Tap the rail carefully to raise it off the dowels.

3 Remove the fixed pivot plate, the rack, and the rail together.



4 Remove the stop from the end of the rail and slide the rail off the rack.

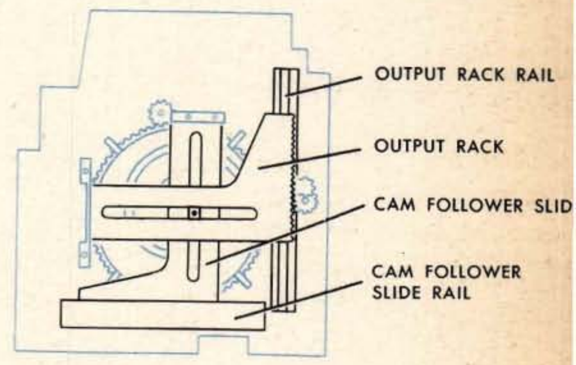
5 Remove the carriage block from the fixed pivot stud. (Usually a snap ring must be removed from the stud before the carriage block will slide off.) This will separate the pivot arm from the fixed pivot plate.



6 Remove the channel from the arm.

7 Remove the screws which hold the output rack rail, and lift off the rack and the rail together. Keep the slide block with the rack.

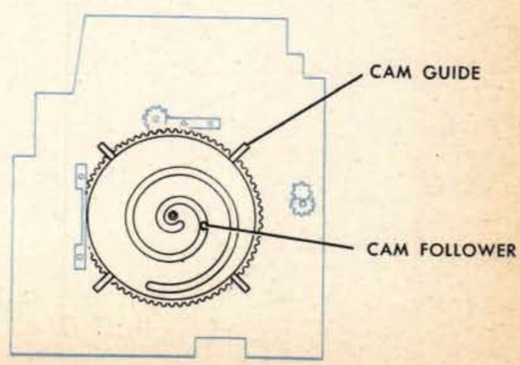
8 Remove the screws which hold the remaining slide rail and lift off the slide and the rail together.



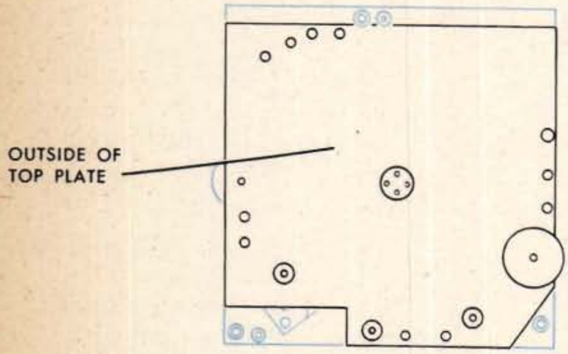
9 Remove the cam follower from the groove.

10 Remove the four cam guides.

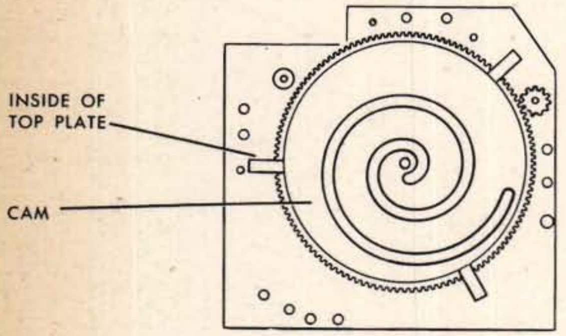
11 Study the assembly drawing before removing the cam, because there are several methods of fastening a cam in place. Remove the cam.



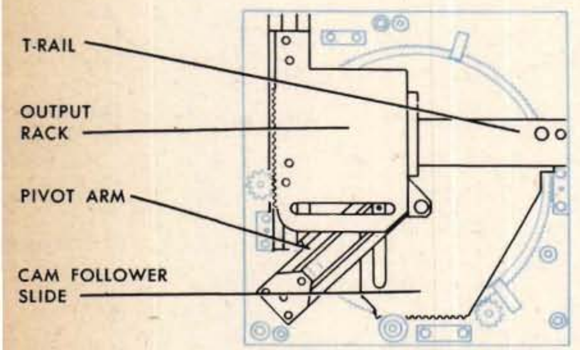
Disassembling the double cam unit



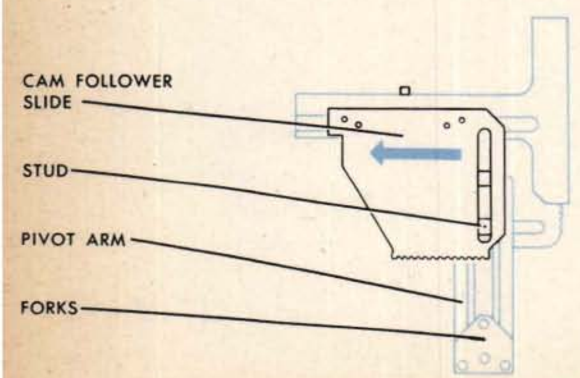
1 Remove the screws that hold the top plate to the posts.



2 Lift off the top plate and cam together. Do not remove the cam from the plate unless the cam is to be replaced.



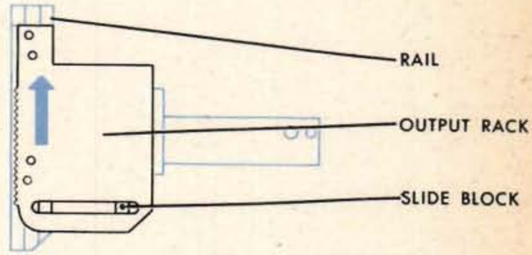
3 Remove the screws holding the T-shaped rail and carefully lift off the assembly consisting of the rail, the output rack, the pivot arm, and the cam follower slide.



4 Place this assembly on the bench with the cam follower slide on top. Raise the end of this slide high enough to clear the stud and take the slide off the rail.

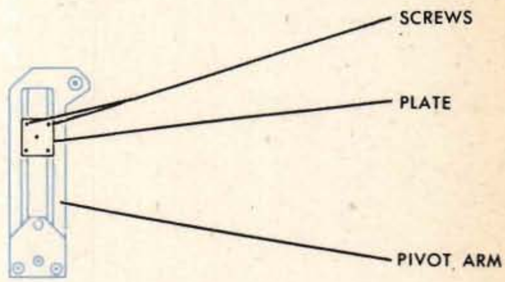
5 Lift off the pivot arm. Do not remove the two forks from the pivot arm unless they are to be replaced.

6 Slide the output rack off the rail.



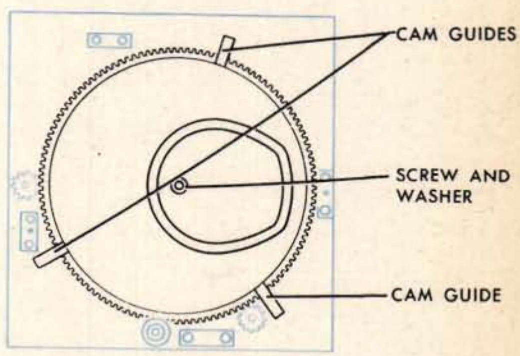
7 Note the way the slide blocks are mounted in the racks. Tie each block to the rack in which it slides.

8 Remove the four flat-head screws that hold the plate to the slide block in the pivot arm. Lift off the plate and the slide block.

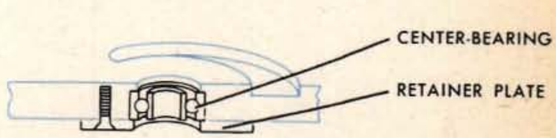


TO REMOVE EITHER CAM

9 To remove either cam from its plate, remove the center flat-head screw and washer and the guides which are on the outside edges of the cam. Lift the cam straight up.

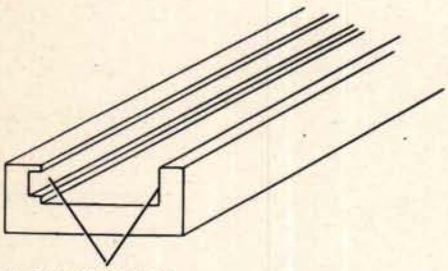


10 The cam center-bearing may be removed after the retainer plate on the back of the cam is removed.



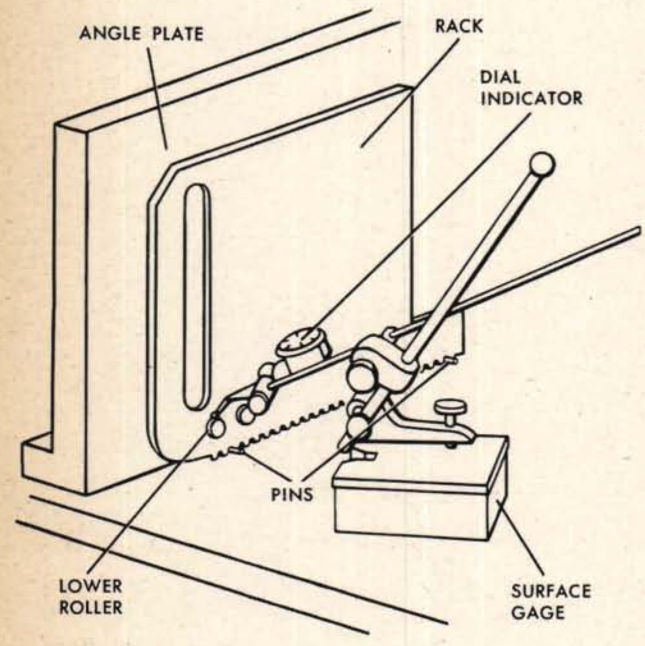
Repairing the parts

Repairing a rail



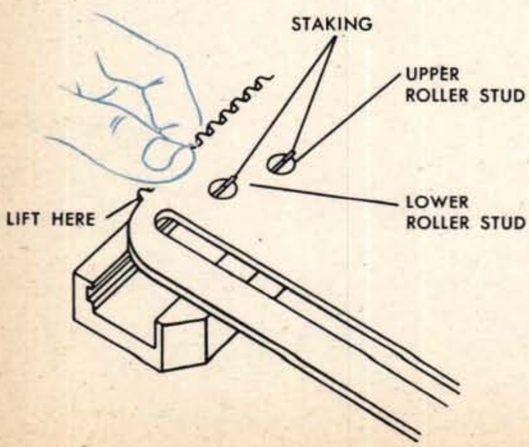
First clean the roller paths in the rail and look carefully for embedded foreign material. Then check the straightness of the roller path. Polish any rough or high spots by stroking the roller path with a square steel bar wrapped in crocus cloth, trying the rack in the rail frequently until a good fit is obtained. After completing this work, wash all the parts thoroughly with an approved solvent.

Adjusting the rollers



The lower rollers establish the pitch line of the rack in relation to its meshing gear. These rollers affect the squareness of the rack slots with respect to each other. Remove the rack and mount it against an angle plate on a surface plate. Support the rack under the teeth, using two identical pins between 0.070 and 0.075 inch in diameter. Place a pin at each end of the rack. With a surface gage and a dial indicator, measure the height of the lower rollers. The heights of these rollers must agree with the assembly drawing and be within 0.0005 inch of each other.

Double cam multiplier slide rollers are positioned a specified distance from the cam follower stud. If the slide has teeth, the lower rollers must be equal distances from the pitch line. After these rollers are repositioned, the racks and slides must be checked for squareness.



The upper rollers control the play between the rack and the rail. If the play exceeds 0.001 inch, turn the roller studs with a screw driver. A strip of feeler gage material (0.001 inch) can be used to check the clearance between the roller and the roller path. After positioning the rollers, stake a small amount of metal into the screw-driver slots of the stud heads. The rollers should be free enough in the rail for the rack to drop back of its own weight if it is raised slightly with one finger.

For an explanation of removing and replacing a riveted stud, see pages 77-79.

Squaring the rack and the slide

In both types of cam multipliers, the slots in the output rack and in the cam follower slide must be at right angles to each other.

Reassemble on the plate the output rack, the slide, the rails, and the guides. Do not reassemble the other parts of the multipliers.

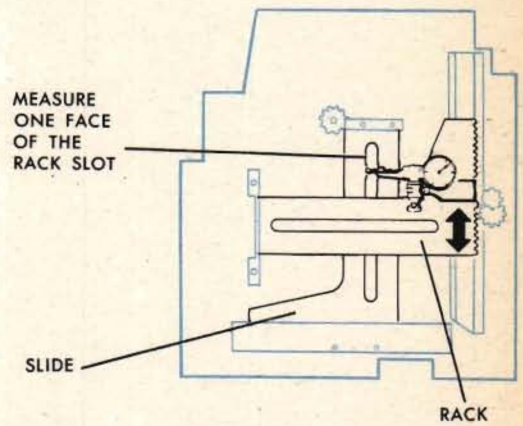
Wedge the slide. Mount a dial indicator firmly on the rack with its point on one face of the slide slot. Move the rack through its full travel and observe the reading as the point of the indicator moves along the face of the slot in the slide. Repeat this procedure with the rack wedged and the indicator mounted on the slide with its point against the face of the rack slot. If the total reading in either case exceeds 0.002 inch in 6 inches of travel, follow the instructions on the preceding page to check the setting of the lower rollers of the rack and the slide. Replace the rack and the slide and repeat the check for squareness.

In the single cam multiplier, if the reading still exceeds 0.002 inch, reposition the slide rail. First, drive the dowels out of the rail. Then replace the rail and its slide and repeat the check for squareness. If the indicator reading is still excessive, loosen the screws holding the rail, and move the rail within the clearance of its screw holes until a reading of 0.002 inch or less is obtained. Then tighten the screws and redowel the rail with oversize dowels

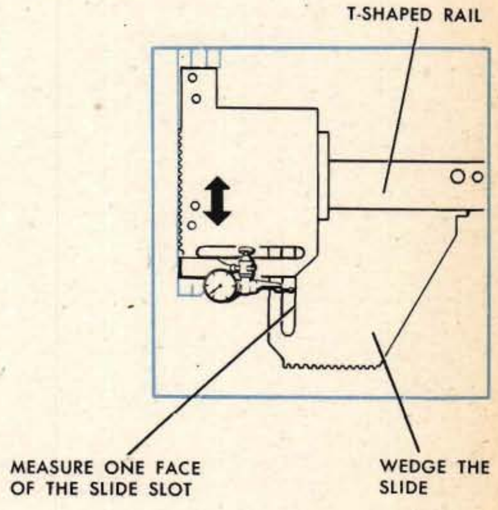
NOTE:

In a double cam unit the rack and slide roller paths cannot be repositioned with respect to each other because they are milled in one T-shaped piece of metal. Proper adjustment of the rollers assures the squareness of the slot in the rack to the slot in the slide.

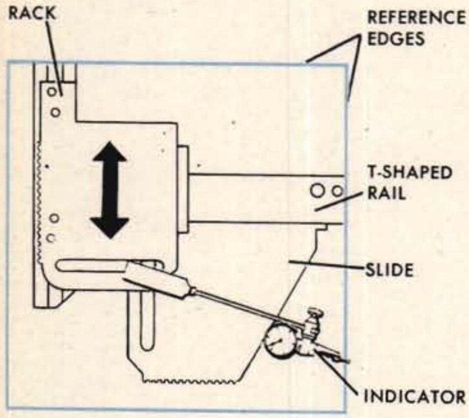
SINGLE CAM UNIT



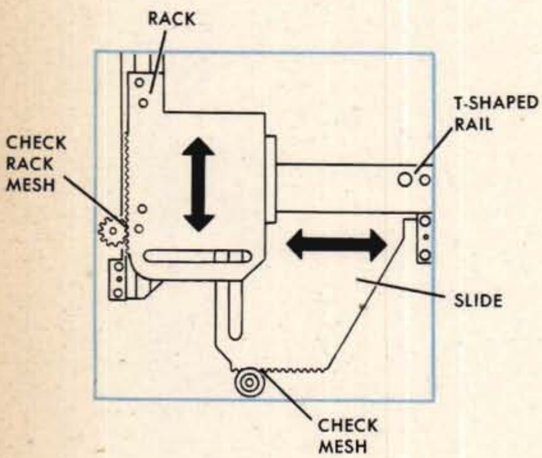
DOUBLE CAM UNIT



Positioning the T-shaped rail



In order to obtain the correct output from the double cam multiplier, the T-shaped rail must be positioned so that the rack slot will be parallel to the reference edge of the plate and so that the gear meshes at the rack and at the slide will be free, yet have a minimum amount of lost motion. Before attempting to position the rail, check that the rollers on the rack and on the slide are adjusted precisely. (Instructions for adjusting the rollers are given on page 234.)

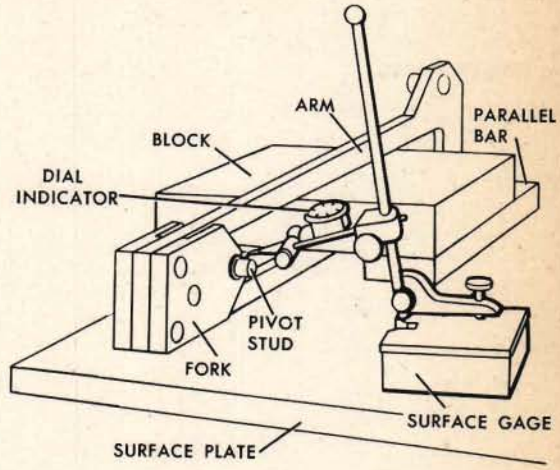


Reassemble the output rack, the slide, and the T-shaped rail on the plate. Do not mount the cams. Clamp an indicator on the output rack with its point against the reference edge of the plate. Run the rack between the limits of its travel. The plate and rail should be parallel within 0.001 inch. If the indicator reading exceeds 0.001 inch, loosen the screws and move the rail within the clearance of its screw holes until a better reading is obtained. Remove the indicator and temporarily replace the top plate. Try the rack and pinion meshes. If the meshes are free, with a minimum of lost motion, remove the plate, tighten the screws, and redowel the rail with oversize dowels.

If the meshes are not correct, shift the rail until good meshes are obtained. Remove the top plate and recheck that the rack slot is parallel to the edge of the plate. Check the meshes again. When these two requirements are met, redowel the rail with oversize dowels.

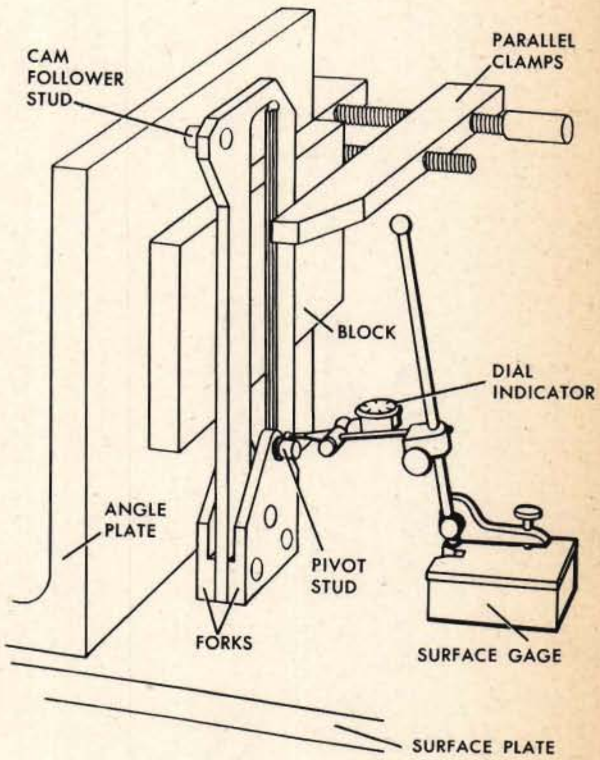
Repairing the pivot studs

If the pivot studs are badly damaged, the accuracy of the multiplier will be affected and the studs should be replaced. Follow the instructions for removing and riveting studs, pages 77-79. Mount the fork on the arm. Check that the pivot studs are centered over the centerline of the slot in the arm, that they are concentric and that they are at the correct distance from the cam follower stud.



Fit a long block into the slot. Place the block between two parallel bars on a surface plate. With a dial indicator mounted on a surface gage, measure the height of the pivot studs. Invert the bar and arm and again measure the height of the studs. The four measurements should agree within 0.0005 inch. This checks the studs with reference to the centerline of the slot and partially checks their concentricity.

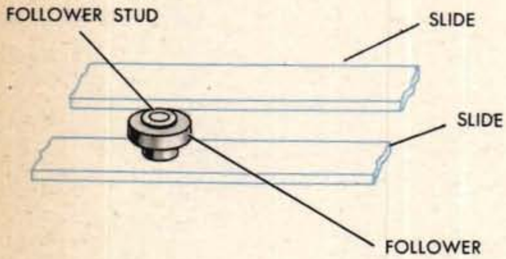
Clamp the arm against an angle plate and measure the height of the studs. The two measurements should agree within 0.0005 inch. This completes the check for the concentricity of the studs.



Refer to the drawings for the distance between the cam follower stud and the pivot studs. With the arm mounted as shown in the lower illustration, use a height gage to measure this distance.

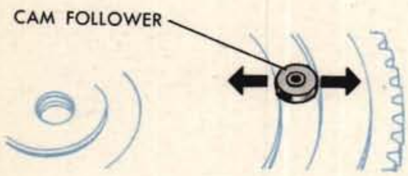
If any one of the requirements is not met, remove the forks, drive out the dowel pins, and reassemble the parts. Shift the forks in the screw clearance holes until all requirements are met. Tighten the screws and redowel with oversize dowels. Check the studs again after doweling.

Checking a cam and its follower



The cam follower should turn freely on the stud without lost motion. Inspect all wearing surfaces of the follower and the stud to be sure they are smooth and polished. Replace either part if its surfaces are scratched or badly worn.

Clean the cam groove with tissue and inspect it for damage and wear. If the sides of the groove are worn deeply or dented, replace the cam.



Lost motion between the follower and the groove should not greatly exceed the allowable maximum shown on the assembly drawing. Place the follower in the groove and check lost motion by observing side play along the full length of the groove. Excessive lost motion requires replacing the follower or the cam.

With the follower in the groove, tilt the cam at about 45 degrees. At this angle, the follower should move along the groove. Turn the cam to keep the follower moving. Mark the face of the cam with a pencil to indicate tight spots in the groove.

If the faces of the groove are rough or pitted, burnish or rub metal into the depressions with a hand burnisher before polishing the tight spots.

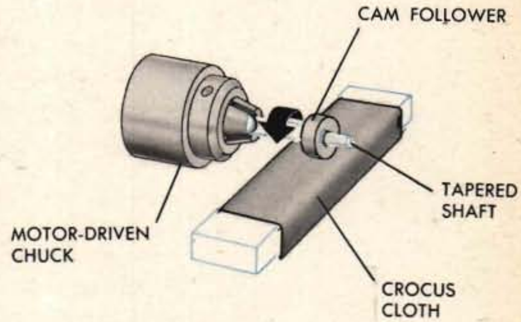
Polish the tight spots in the groove with crocus cloth wrapped around a steel bar. Try the follower often in order to obtain the best possible fit.

Fitting a new follower

Use a fine oilstone to smooth burred or rough edges of the follower. Remove any extremely sharp edges, but leave them square. It is very important not to round or chamfer the edges.

Polish the stud to fit the hole in the follower. The follower should turn smoothly on the stud without lost motion.

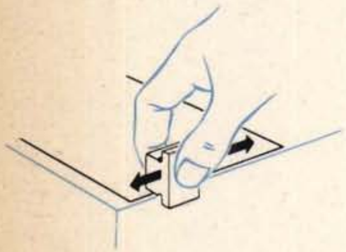
Fit the follower to the widest part of the groove. To reduce the width of the follower, polish it with crocus cloth. Mount it on a slightly tapered shaft held in a slow-speed motor-driven chuck. As the follower turns, polish it against crocus cloth wrapped around a metal block. Try the follower in the groove frequently until it just fits the widest part without lost motion.



Polish down all other parts of the groove to fit the follower, using crocus cloth wrapped around a metal bar. Continue polishing only until the follower will move freely throughout its length without lost motion. Thoroughly clean both the follower and the groove with an approved solvent.

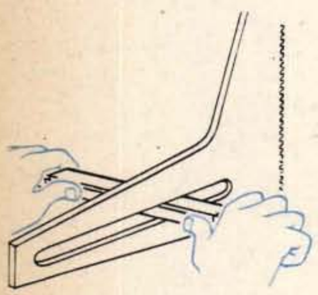
Run the follower back and forth in the groove to burnish off any remaining *slight* high spots. When the fitting has been completed, lubricate the follower and groove with an approved lubricant.

Fitting a rack slide block



Use a fine oilstone to smooth burred or rough edges of the block. Remove any extremely sharp edges, but leave them square. It is very important not to round or chamfer the edges.

To reduce the width of the block, polish the sides on a piece of crocus cloth placed on a flat surface. Be sure to remove equal amounts from both sides so that the hole remains perfectly centered. Use long, even strokes while holding the block square. Measure it occasionally with a micrometer to be certain that the sides are parallel.



Polish the block until it is a close fit in the widest part of the slot. Polish the rest of the slot to fit the block, using crocus cloth wrapped once around a steel bar. Be sure to keep the sides of the slot parallel and flat.

Before trying the block in the slot, thoroughly wash, dry, and lubricate them both. The fit is correct when the block can be moved the full length of the slot. Move the block back and forth by hand until it travels smoothly from one end to the other. Finally, wash the block and slot again with an approved solvent, and apply an approved lubricant to the slot.

Replacing a fixed pivot stud

SCREW-FASTENED STUD

Fixed pivot studs are either riveted to the fixed pivot plate, using one end of the stud as a rivet, or fastened to the plate with screws.

A screw-fastened stud can be removed by taking out the screws.

RIVETED STUD

A riveted stud can be removed by drilling into the stud with a center drill until the peened-over portion of the stud is removed. Be sure to use a support under the stud to avoid bending or distorting the plate. For a detailed explanation of removing and replacing parts which are riveted in this way, see pages 77-79.

If necessary, polish the new stud so that it will move freely in the hole in the slide block with a minimum of lost motion. Adjust the distance between the stud and the center of the pivot disk during final assembly of the unit.

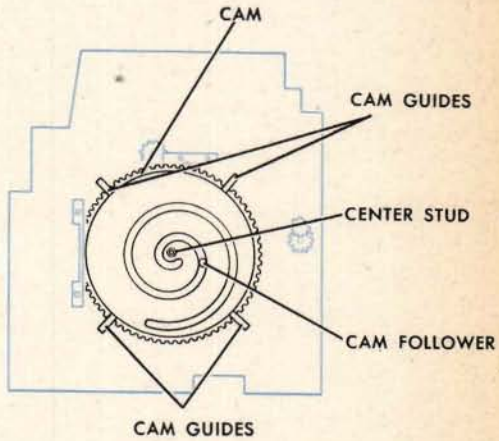
Reassembling the single cam unit

Wash all parts with an approved solvent and dry them before beginning to reassemble the unit. Lubricate each piece before assembling it. After mounting each part, check for lost motion and smoothness of operation.

1 Replace the cam on the center stud.

2 Replace the four cam guides.

3 Place the follower in the cam groove.

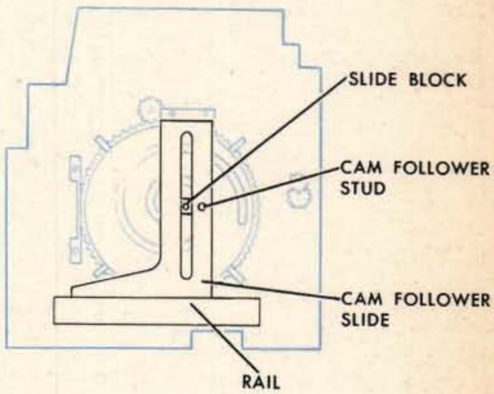


4 Move the cam follower slide onto its rail.

5 Mount the slide and rail on the plate.

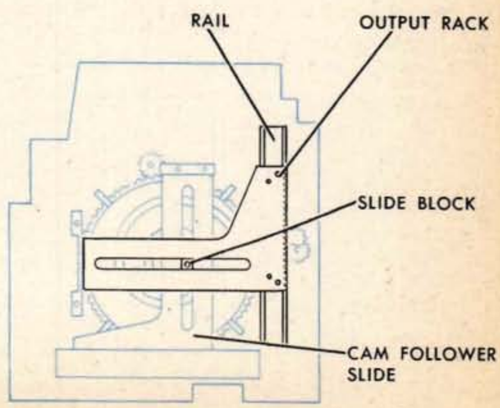
6 Turn the cam and move the slide until the cam follower stud drops into the follower. *Caution: Be careful not to damage the cam groove with the sharp edge of the stud.*

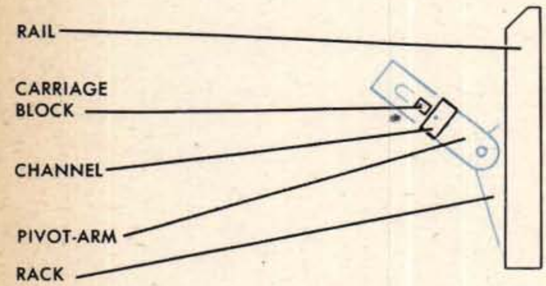
7 Place the slide block in the slide slot.



8 Move the output rack onto its rail and fasten the rail in place.

9 Place the slide block in its slot and position it over the lower slide block.

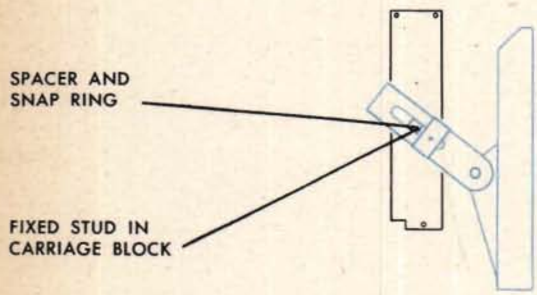




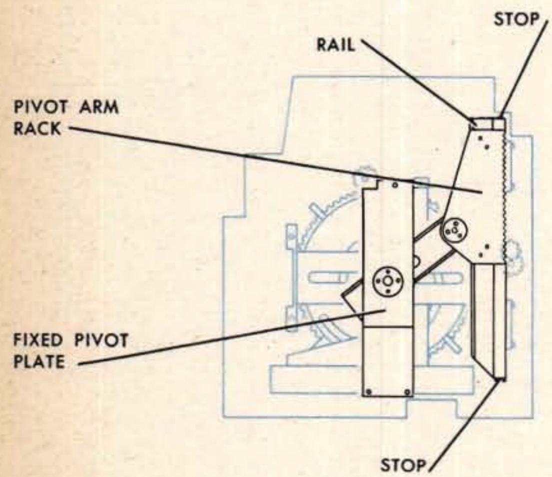
10 Slide the pivot-arm rack into the rail.

11 Slide the channel onto the pivot arm.

12 Place the carriage block in the pivot-arm slot.



13 Insert the fixed stud into the carriage block. If a spacer and snap ring were used as a retainer, replace them on the fixed stud at this time.



14 Lift the plate and pivot-arm assembly and fit it in place on the multiplier assembly, inserting the channel stud through both slide blocks. Secure the plate and rail to the main plate.

15 Replace the stops on the ends of the rail.

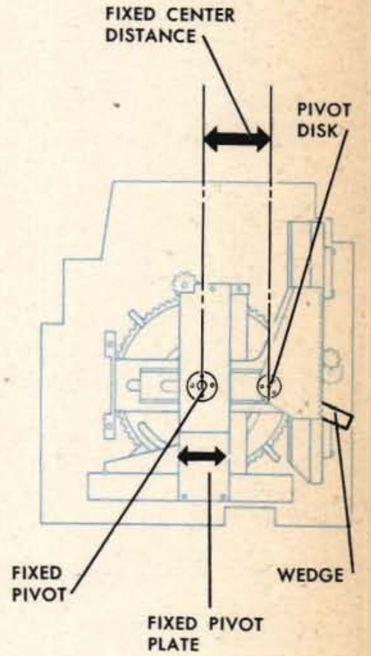
Setting the fixed center distance

To facilitate the measurement of the fixed center distance, small holes of accurate diameter and location are usually provided in the center of the multiplier pivot disk and in the fixed pivot. When two pins of the proper diameter are placed in these holes, the center distance can be measured with a vernier caliper. Consult the assembly drawing for the required distance between the fixed pivot and the line of travel of the center of the pivot disk. When making this measurement, the slot in the pivot arm should be in line with the slot in the output rack. A bakelite wedge may be used to hold the pivot-arm rack in this position.

If a concentric pivot stud is used, reposition the bridge to adjust the distance. Remove the dowels in the bridge, reposition the bridge to establish the correct distance, and redowel the bridge with oversize dowels.

If an eccentric pivot stud is used, turn it to the correct position. Do not forget to stake a small amount of metal into the screwdriver slot to hold the stud in position.

Remove the bakelite wedge. Move the cam and the input rack through their full travel to check for smoothness and lost motion.



Bench checking the unit

1 Check the assembly of the unit against the assembly drawing.

2 All eccentric studs should have been staked to hold them in position.

3 The cam follower should travel freely and without lost motion from one end of the cam groove to the other.

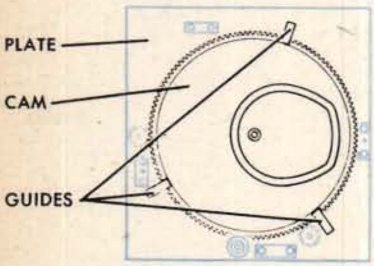
4 Lost motion between slides and rails should be at a minimum. The maximum lost motion is indicated on the assembly drawing.

5 The distance between the fixed pivot and the input-arm pivot must be within the limits shown on the assembly drawing.

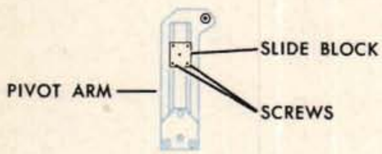
6 The pivot-arm rack must move freely through its full travel.

Reassembling the double cam unit

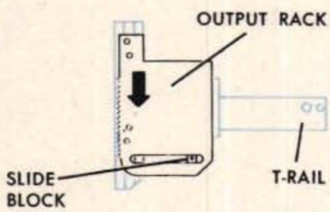
Wash all parts with an approved solvent and dry them before beginning to reassemble the unit. Lubricate each piece before assembling it. After mounting each part, check for lost motion and smoothness of operation.



1 Replace each cam on its plate. Replace the guides.

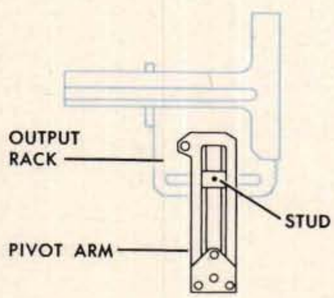


2 Replace the slide block in the pivot arm. Stake the flat-head screws.

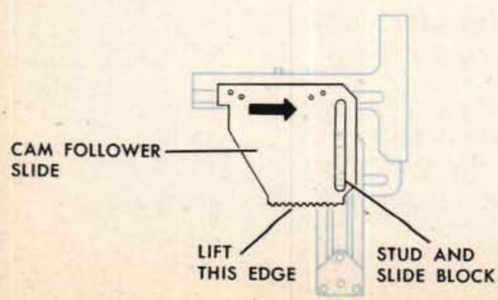


3 Slide the output rack onto the T-shaped rail.

4 Turn the output rack and rail assembly over and replace the slide block in the rack slot.

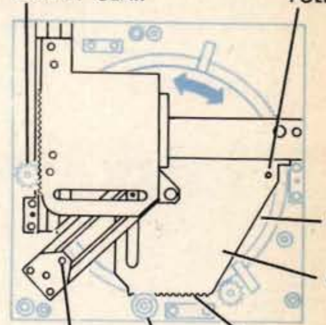


5 Hold the pivot arm over the output rack with the multiplier stud centered over the slide block in the rack. Lower the pivot arm into position so that the stud goes into the output-rack slide block.



6 Replace the slide block of the cam follower slide on the multiplier stud.

7 Fit the cam follower slide into its rail, raising the end to clear the stud.

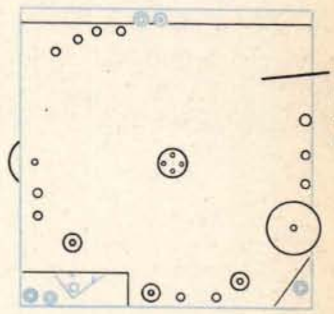


8 Turn the assembly over and position it carefully over the lower plate. Support the assembly above the plate and turn the lower cam until the cam follower in the lower rack drops into the cam groove.

9 Lower the assembly into place. If an intermediate output is taken from the square-cam follower slide, carefully mesh the rack teeth on the slide with the mating gear. Guide the pivot stud on the fork of the pivot arm into its bearing in the lower plate.

10 Check the assembled parts for freedom of movement before fastening the rail.

11 Position the upper plate and cam over the assembly. Turn the upper cam and move the pivot arm until the cam follower in the pivot arm lines up with the cam groove. Lower the top plate and the cam into position.



12 Turn both cams to check for smoothness of operation before replacing the screws in the top plate.

Recheck the unit for smoothness of operation and correct fit by turning both cams through their full travel.

Bench checking the unit

1 Check the assembly of the unit against the assembly drawing.

2 There should be no binding or sticking throughout the full travel of both cams.

3 Lost motion between racks and rails should be reduced to a minimum. The allowable maximum is indicated on the assembly drawing.

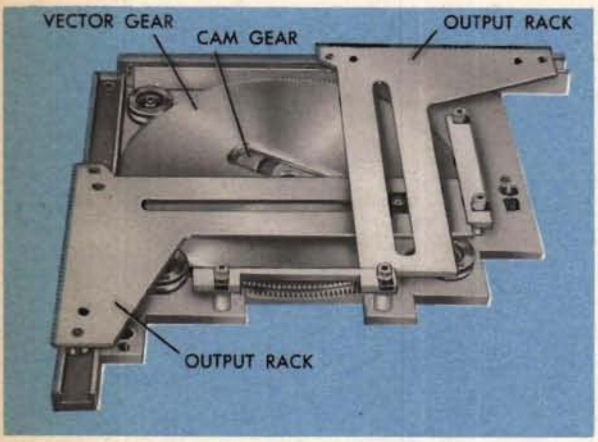
4 Lost motion between followers and cams and between rack slots and pivot studs should be reduced to a minimum. The allowable maximum is indicated on the assembly drawing.

5 Both input gears should mesh properly with their cams throughout the full travel of the cams.

6 When the lower cam follower is at the inner limit of the cam groove, there should be no motion of the output rack as the upper cam is turned through its full travel. The allowable maximum is indicated on the assembly drawing.

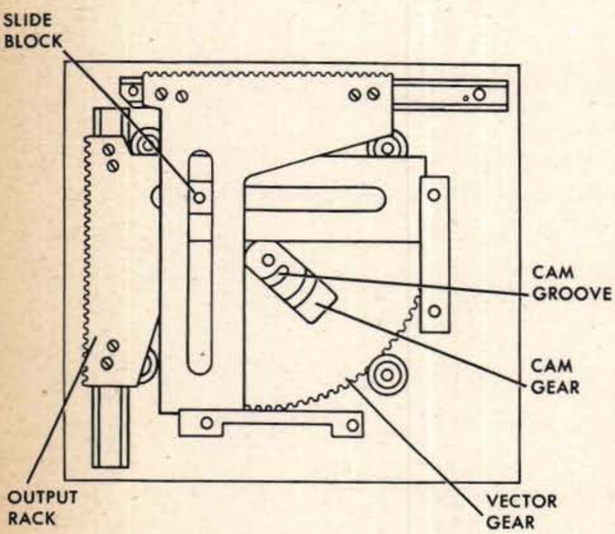
7 Check the effect of upper cam positioning on movement of the output rack, as indicated on the assembly drawing.

THE CAM TYPE COMPONENT SOLVER



A cam type component solver is usually mounted on a separate base plate, with the output and input gears at the sides of the unit. The *inputs* are carried by the cam gear and the vector gear. The *outputs* are carried by the two racks.

In order to remove the cam type component solver, other units and gearing groups often must be removed first. For this reason, the exact source of the trouble in the unit should be located before removal is considered. If the unit must be removed for repair, consult the instrument OP for instructions.



Typical symptoms

If a test analysis and unit check test indicate that a cam type component solver is not operating normally, look for one or more of the following typical symptoms:

JAMMING: The cam, the vector gear, or one or both of the racks cannot be moved by hand.

STICKING: The cam, vector gear, or racks move sluggishly, or resist moving past certain points.

EXCESSIVE LOST MOTION: There is too much play between a rack and rail, the cam follower and cam groove, or the vector gear is loose in its guide rollers.

SLIPPING: Moving the cam and the vector gear results in only intermittent movement or in no movement of the output racks.

Locating the cause

Cam: jamming or sticking

The cam may be jammed at either end of its travel because the follower has driven against the end of the groove and bent the follower stud. To replace a bent follower stud it is necessary to disassemble the unit. This type of jamming is usually caused by an improperly adjusted limit stop in the cam input shaft line. The instrument OP gives directions for the proper adjustment of this limit stop.

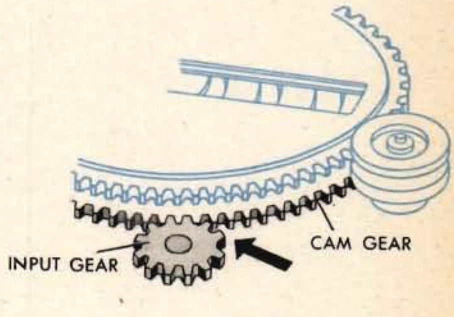
A cam may jam or stick within its normal travel because of damaged or dirty teeth on the cam rim, a sticking guide roller, a bent follower stud, or a cam follower locked in its groove because of damage or dirt.

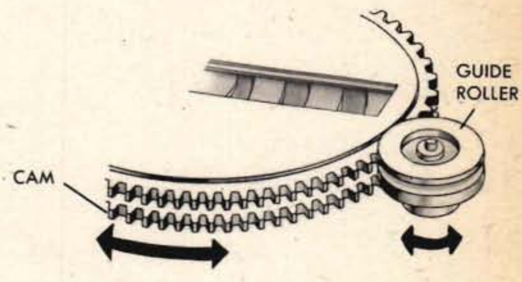
To check for jamming or sticking of the cam rim, inspect the mesh between the cam and its meshing gear. Damaged or dirty teeth usually can be repaired in place.

To check for a sticking guide roller, turn the cam through its travel several times and watch each of the four guide rollers in turn. Sticking may occur once for each revolution of the cam or of a guide roller. Sticking caused by a small burr or nick on the cam or a guide roller can often be repaired in place by filing or polishing. If the cam of a follower is damaged enough to require replacement, the unit must be disassembled.

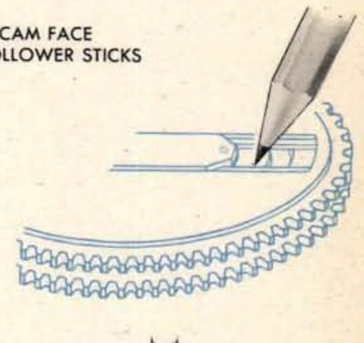
To check for a sticking cam follower, turn the cam again and observe the position of the follower in the cam groove. If the follower always sticks at the same place in the groove, mark the spot and inspect the groove carefully for damage. Wipe the groove clean with tissue, remove embedded particles, and polish the tight or rough spot. Be careful to avoid enlarging the groove. Thoroughly clean and lubricate the groove before turning the cam to check for smoothness.

If sticking does not always occur at the same place, the trouble may be caused by the cam follower or the cam follower stud. The unit must be disassembled to repair these parts.

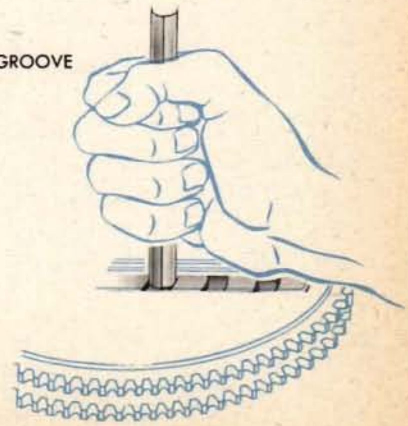


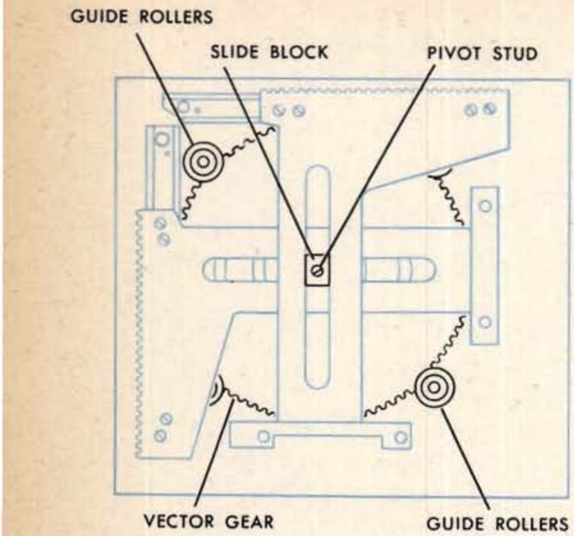


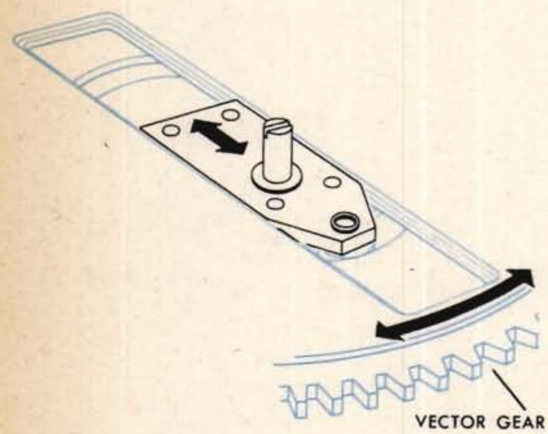
MARKING THE CAM FACE WHERE THE FOLLOWER STICKS

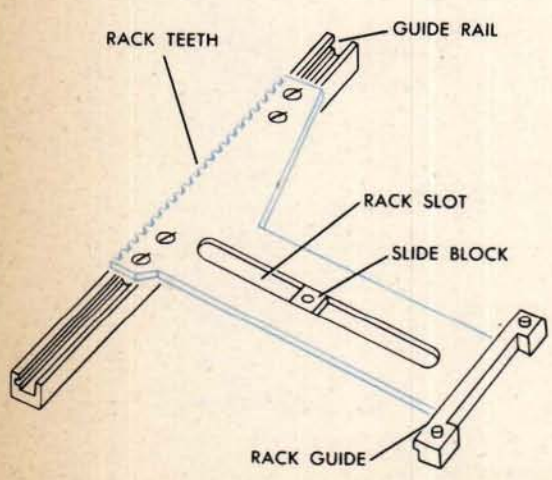


POLISHING THE CAM GROOVE









Vector gear: jamming or sticking

A vector gear may jam or stick because of damaged or dirty gear teeth or guide rollers. Dirt, burrs, or nicks in the gear teeth can sometimes be removed without disassembling the unit. If the vector gear sticks in the guide rollers, the roller assemblies can sometimes be washed and lubricated in place. If the guide rollers must be removed, the unit should be disassembled.

The vector gear may not turn or may turn sluggishly because the slide blocks jam or stick on the pivot stud. Inspect these blocks for jamming or sticking. The block in the slot of the outside rack can be repaired without disassembling the entire unit.

If the carriage block can be moved when the vector gear is jammed, the trouble may be due to dirty or damaged gear teeth. Often the vector gear can be moved from its jammed position by hand and cleaned and lubricated without disassembling the unit. Turn the vector gear to inspect the teeth for dirt or damage.

Racks: jamming or sticking

A rack may jam or stick because of a dirty or damaged rack guide, guide rail, rack roller, rack slot, sliding block, or defective gear teeth. Slight damage may be repaired and the parts cleaned and lubricated without disassembling the unit. Improper positioning of the rollers may cause them to jam or stick in the rails, or make too tight a mesh between the rack and pinion. Shake the rack to check lost motion between the roller and rail. Usually a block which sticks slightly in a rack slot can be restored to normal operation by cleaning and lubricating the sliding surfaces and running the parts back and forth to work them in smoothly. Disassemble the unit for repair only if it sticks enough to cause serious errors in the operation of the instrument.

If neither rack can be moved and the cause is not found in the parts in contact with the racks, the cause may be a jammed cam, carriage block, or vector gear.

Excessive lost motion

Excessive lost motion of the racks may be caused by worn parts or a loose roller stud. Shake each rack to check that the lost motion does not exceed the limits given on the assembly drawing. If excessive lost motion is detected, reposition the rollers which are located away from the rack teeth.

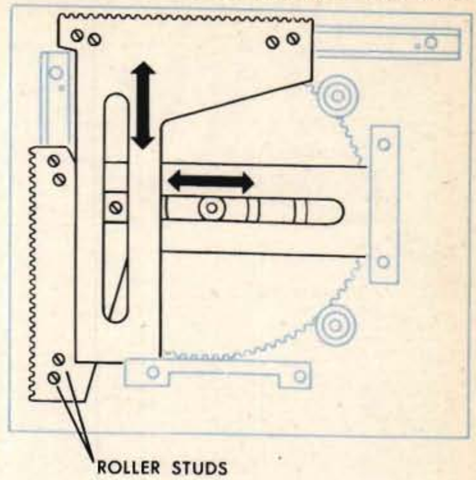
Lost motion between both racks and the cam and the vector gear can be checked in one operation. Position the cam and the vector gear at various points within their travel and shake both racks at each position. Lost motion may be caused by a worn slide block or slot, or by a worn follower in the cam groove. To eliminate such lost motion, the unit must be disassembled and the worn parts replaced.

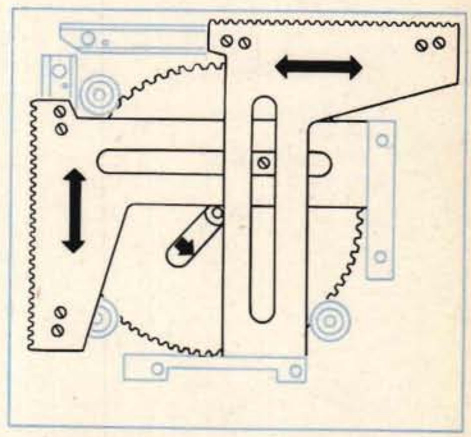
Shake the vector gear to check for side play. Any noticeable side play is caused by improper adjustment of the four guide rollers. To reposition the rollers, the unit should be disassembled and the eccentric studs repositioned. Excessive side play should be eliminated at the same time the vector gear is centered.

Slipping

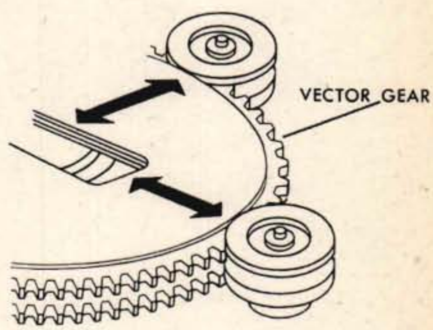
If moving the input cam and the vector gear results in only intermittent movement or in no movement of the output racks, the trouble may be caused by stripped rack teeth or a broken pivot or follower stud. A rack with stripped teeth should be replaced. To inspect for a loose or sheared pivot or follower stud, move the racks through their full travel by turning the cam and the vector gear *alternately*. If either rack does not move smoothly, the unit should be disassembled to repair or replace the faulty stud.

SHAKING THE RACKS TO CHECK FOR LOST MOTION

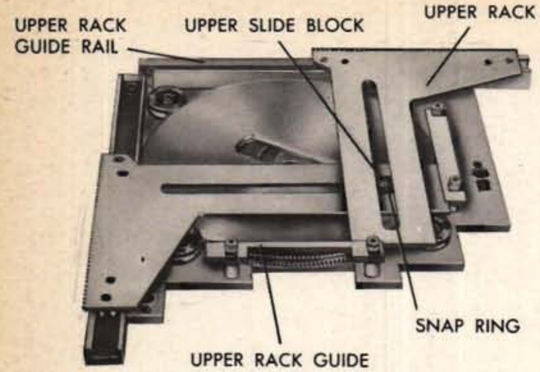


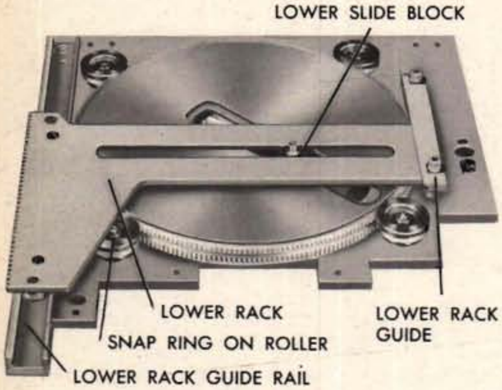


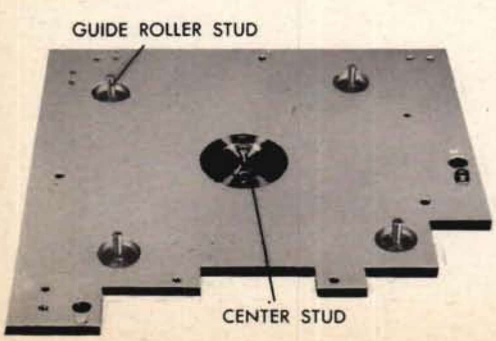
POSITIONING CAM AND VECTOR GEAR AT VARIOUS POINTS AND SHAKING THE RACKS



CHECKING THE VECTOR GEAR SIDE PLAY







Disassembling the unit

1 Remove the snap ring and spacer from the slide block stud.

2 Remove the screws holding the upper rack guide and guide rail. Lift off the guide, rack, and rail together.

3 Lift off the upper slide block. Keep it with its rack.

4 Remove the lower rack together with its guide rail and rack guide.

5 Lift off the lower slide block. Keep it with its rack.

6 Remove the snap rings from the four support rollers.

7 Mark each stud and its roller to simplify reassembly.

8 Lift off the four rollers and the vector gear, being very careful not to cock the gear. This operation requires two men.

9 Lift out the cam follower.

10 Remove the cam. Usually the bearing is held by a retainer on the under side of the cam, but it is fastened in different ways on different units. Study the assembly drawing before attempting to remove the cam.

11 Turn the vector gear over and remove the four flat-head screws which hold the retainer plate to the carriage block. Lift off the carriage block and retainer plate.

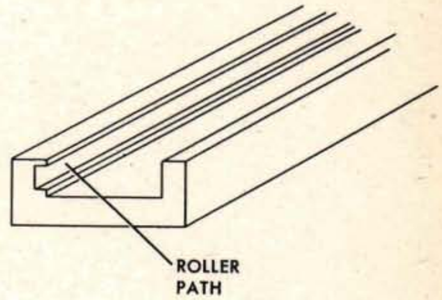
12 Remove the center stud.

13 Do not remove the four guide roller studs unless the vector gear is not centered or has excessive side play.

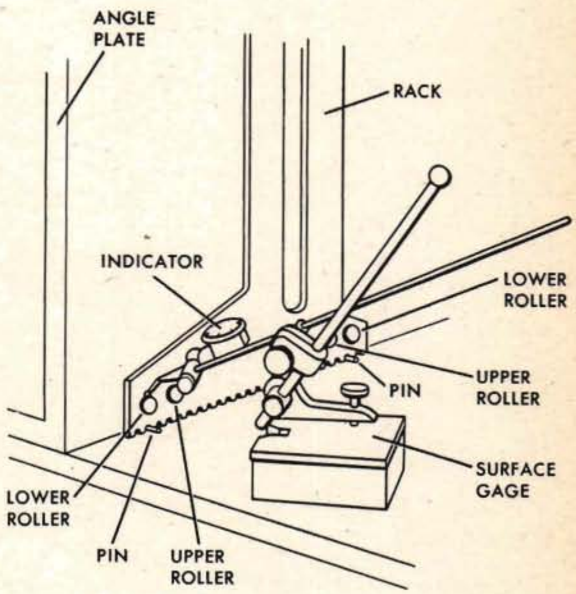
Repairing the parts

Repairing a rail

First use tissue to clean the roller path in the rail. Carefully remove any embedded foreign material. Then check the straightness of the roller path, and if necessary polish rough or high spots with crocus cloth, trying the rack in the rail frequently until a good fit is obtained. After completing this work, clean the parts thoroughly with solvent and lubricate them.

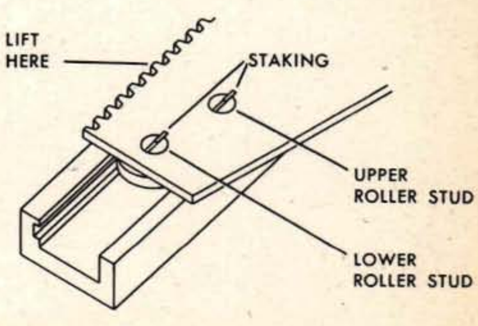


Adjusting the rack rollers



The lower rollers position the pitch line of the rack in relation to its meshing gear. These rollers affect the alignment of the rack slots as well as the mesh of the rack and the gear. Remove the rack and mount it against an angle plate on a surface plate. Support the rack under the teeth, using two identical pins between 0.070 and 0.075 inch in diameter. Place a pin under each end of the rack. With a surface gage and a dial indicator, measure the height of the lower rollers. The heights of these rollers must agree with the assembly drawing and be within 0.0002 inch of each other.

The upper rollers control the play between the rack and its rail. The play should not exceed 0.0005 inch. A strip of feeler gage material (0.001 inch) can be used to check the clearance between the roller and the roller path.

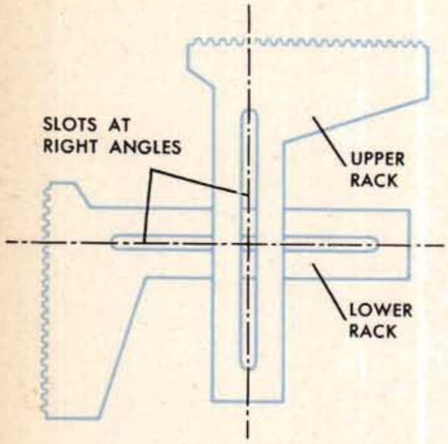


To position the rollers, turn the roller studs with a screw driver. Then stake a small amount of metal into the screw driver slots of the stud heads.

The rollers should be free enough in the rail for the rack to drop back of its own weight if it is raised slightly with one finger.

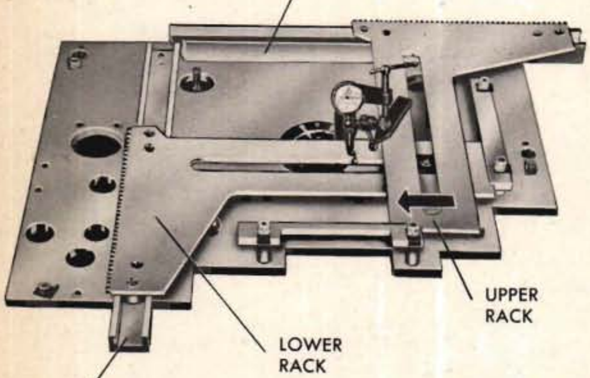
For an explanation of the method of removing and replacing a riveted stud, see page 76.

Squaring the racks



The slots in the upper and lower racks must be at right angles to each other.

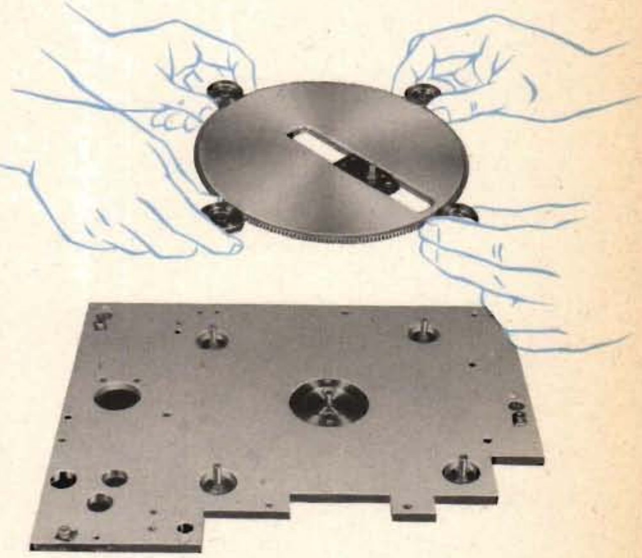
Reassemble on the plate the two racks, their rails and guides. The vector gear and cam gear should not be installed for this operation. Wedge the lower rack to prevent it from moving.



Mount a dial indicator firmly on the top rack with its point on one face of the lower rack slot. Move the upper rack through its full travel and observe the reading as the point of the indicator moves along the face of the slot in the lower rack. If the total reading exceeds 0.001 inch, check the setting of the lower rollers on the lower rack as instructed on page 251. It is advisable to check the lower rollers of the upper rack at the same time. Replace the two racks and repeat the check for squareness. If the indicator reading still exceeds 0.001 inch, reposition one of the rails. To do this, first drive the dowels out of the rail. Then replace the rail and its rack and repeat the check for squareness. If the indicator reading its still excessive, loosen the screws holding the rail, and move the rail within the clearance of its screw holes until a reading of 0.001 inch or less is obtained. Then tighten the screws and redowel the rail with over-size dowels.

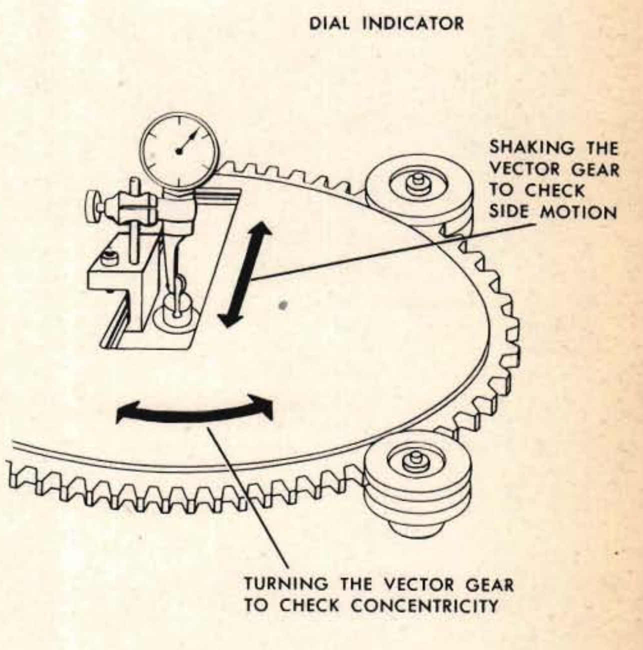
Centering the vector gear

Excessive side play of the vector gear should be eliminated at the same time that the vector gear is centered, so that the vector gear is always kept concentric with the center stud.



First remove the vector gear and the guide rollers. To prevent bending the vector gear, two men are needed to lift the four guide rollers evenly. Remove the cam gear. Unscrew the nuts which secure the roller studs to the plate, remove the studs, and tap out the dowels which position the studs. Replace each stud and hold it loosely in place with the nut. Mount the vector gear and the four guide rollers.

Now mount an indicator firmly on the vector gear with its point against the side of the center stud. Two adjustments are to be made at the same time: The vector gear is to be centered and the guide rollers repositioned to reduce side play. Turn the vector gear one revolution and watch the dial for variations in readings. Turn the eccentric studs to reposition the rollers. Turn the vector gear one revolution and check the variations of dial readings again. When the indicator shows the minimum possible variation, the vector gear should at the same time turn freely but with side play within the limits given on the assembly drawing.

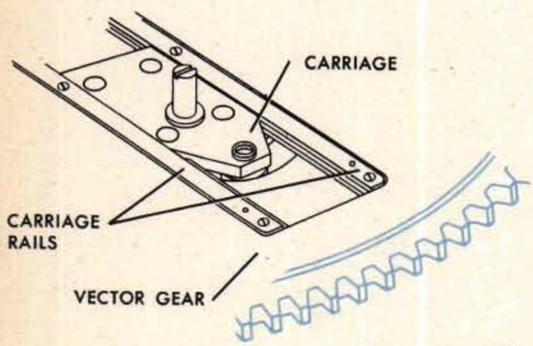


Tighten and stake the nuts holding the studs and remove the rollers and the vector gear. Redowel the studs with oversize dowels.

Reducing lost motion between the vector gear and its spur gear

If there is excessive lost motion between the vector gear and the spur gear, the spur gear should be repositioned. *Never* move the vector gear to reduce lost motion, because doing so will disturb the concentricity of the cam and vector gear.

Adjusting the carriage block and carriage rails



MOUNTING THE VECTOR GEAR ASSEMBLY ON THE PLATE AND CENTERING THE CARRIAGE BLOCK

On large component solvers, adjustable rails are used to reduce lost motion of the carriage block. To adjust the carriage block, first remove the rails and drive out the dowels. Replace the rails and carriage block on the vector gear and adjust the screws holding the rails until the carriage block can be moved through its full travel without lost motion.

The rails cannot yet be redoweled because adjusting them usually disturbs the pivot stud.

Centering a concentric pivot stud

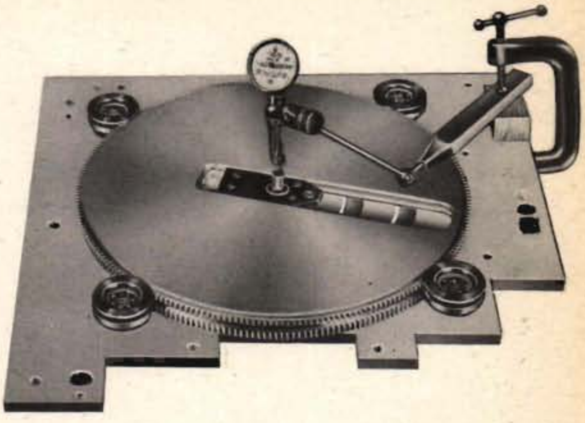
To center the concentric pivot stud in the carriage block of a large component solver, first center the vector gear and eliminate side play according to the instructions on the previous page. Then position the pivot stud by moving the carriage along its rails to the center of the vector gear. Mount a dial indicator on the plate, with the point against the side of the pivot stud. Turn the vector gear one revolution and observe the variation in readings. Reposition the rails until a minimum variation of dial readings is obtained. If necessary, continue repositioning the carriage block and moving the rails until the variation of indicator readings is within the limit allowed by the assembly drawing. When moving the rails, be careful to maintain the fit of the carriage block throughout its travel.

When a final adjustment has been made, tighten the rail screws, remove the vector gear, and redowel the rails with oversize dowels. In fitting the dowels, be careful not to warp the rail.

Centering an eccentric pivot stud

To center the eccentric pivot stud on the carriage block of a small component solver, first center the vector gear and eliminate side play according to the instructions on page 253. The cam and vector gear will then be concentric. Turn the cam until the pivot stud appears to be centered. Now mount an indicator on the plate with its point against the side of the stud and at right angles to the slot. Hold the cam and the vector gear together and turn them 180°. Observe the difference in dial readings. If the difference exceeds the allowable maximum shown on the assembly drawing, turn the stud, being careful not to burr the slot with the screw driver. Reposition the carriage block and repeat the test until excessive lost motion is within the proper limit. Stake the stud to hold it in its new position. Use care in riveting and staking the stud to avoid warping or distorting the carriage block.

For a detailed explanation of removing and replacing parts which are riveted in this way, see pages 77-79



CENTERING AN ECCENTRIC PIVOT STUD

Fitting a new slide block

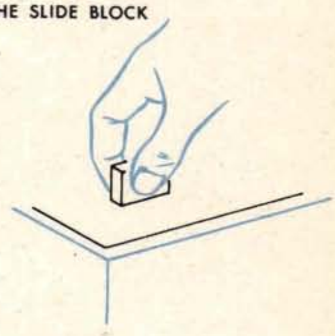
Use a fine oilstone to smooth burred and rough edges of the block. Remove any extremely sharp edges but leave them square. It is very important not to round or chamfer the edges.

To reduce the width of the block, polish the sides on a piece of crocus cloth placed on a flat surface, using long, even strokes while holding the block square. Be sure to remove equal amounts from each side, so that the hole remains perfectly centered. Measure the block occasionally with a micrometer to be certain that the sides are parallel.

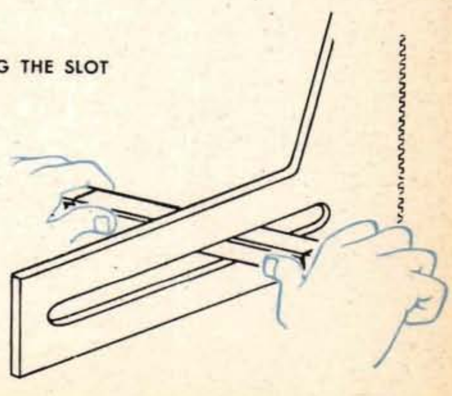
Polish the block until it fits closely in the widest portion of the slot. Polish the rest of the slot to fit the block, using crocus cloth wrapped once around a steel bar. Be sure to keep the slot sides square and flat.

Before trying the block in the slot, thoroughly wash, dry, and lubricate both parts. The fit is correct when the block can be moved the full length of the slot. Move the block back and forth by hand until it travels smoothly from one end to the other. Finally, wash the slot and block again, and lubricate the slot.

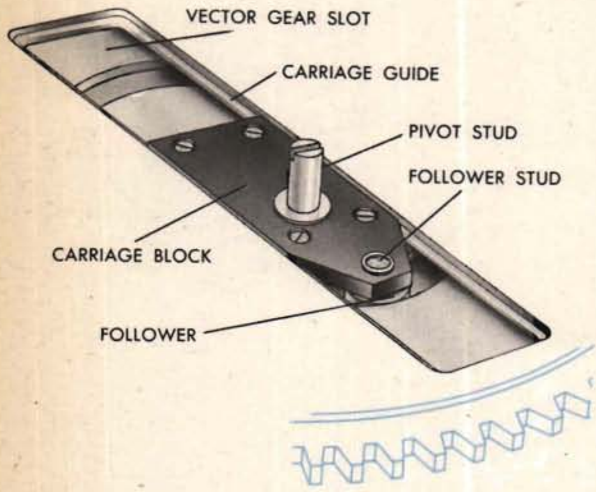
POLISHING THE SLIDE BLOCK



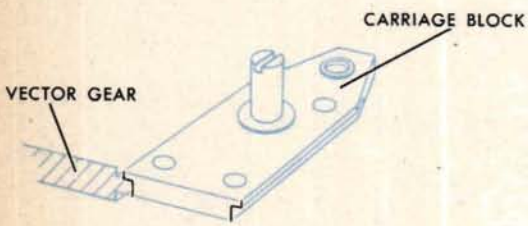
POLISHING THE SLOT



Fitting a new carriage assembly

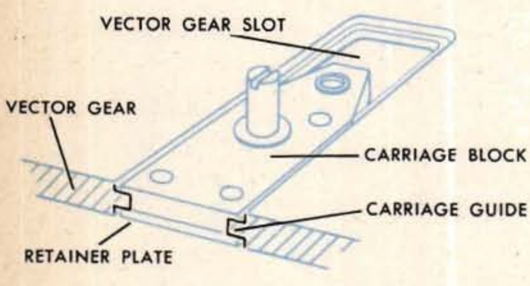


In fitting a new carriage assembly, a new pivot stud must be used. First fit the carriage block between the carriage guides in the vector gear slot. Use a fine oilstone to smooth burred and rough edges of the block. Remove any extremely sharp edges but leave them square. It is very important not to round or chamfer the edges. Try the block on the carriage guides. If necessary, polish the sides of the block on crocus cloth until it fits without lost motion in the widest part of the space between the carriage guides. Remove equal amounts from each side so that the stud hole remains centered. During this operation do not remove material from any surface of the block except the sides which fit between the guides. Measure the block occasionally with a micrometer to be certain that the sides are parallel.



Polish the inner faces of the carriage guides with crocus cloth backed up by a steel bar until the block can be moved freely through the full length of the vector gear slot. Keep the sides square and flat. Clean the guides and the block thoroughly each time before trying them together. Apply a little lubricant, and move the block back and forth by hand until it travels smoothly from one end to the other.

When a new retainer plate is to be fitted, it is mounted with the carriage block on the guides in the vector gear slot. Tighten each of the four screws a little at a time. Each time the screws are tightened, slide the assembly back and forth on the guides.



If the carriage slots are too narrow, the carriage assembly will clamp tightly on the carriage guides when the screws are tightened. Remove the carriage block and polish the surfaces which ride on the guides until the assembly can be moved over the thinnest portion of the guides. Then, if necessary, polish the upper faces of the guides to fit the carriage slots.

If the carriage slots are too wide, polish the bottom of the block to reduce their width. Wash, dry, and grease the parts, reassemble them, and run the assembly back and forth in the slot by hand.

Checking a cam and its follower

The cam follower should turn freely on the stud without lost motion. Inspect all wearing surfaces of the follower and the stud to be sure they are smooth and polished. Replace either part if its surfaces are scratched or badly worn.

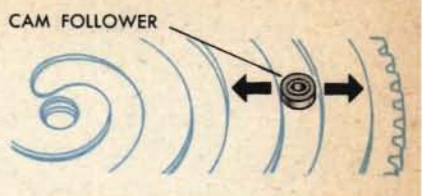
Clean the cam groove with tissue and inspect it for damage and wear. If the sides of the groove are worn deeply or dented, replace the cam, if a replacement is available. If the groove is worn fairly evenly, try an oversize roller.

Lost motion between the follower and the groove should not greatly exceed the allowable maximum shown on the assembly drawing. Place the follower in the groove and check lost motion by observing side play along the full length of the groove. Excessive lost motion requires replacing either the follower or the cam.

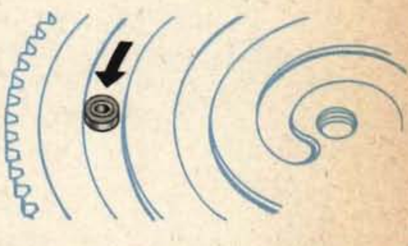
With the follower in the groove, tilt the cam at about 45°. At this angle, the follower should move along the groove. Turn the cam to keep the follower moving. Mark the face of the cam with a pencil to indicate tight spots in the groove.

If the faces of the groove are rough or pitted, burnish or rub metal into the depressions with a hand burnisher before polishing the tight spots.

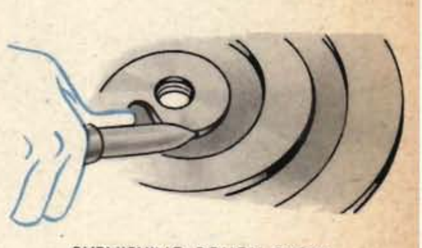
Polish the tight spots in the groove with crocus cloth wrapped around a steel bar. Try the follower often in order to obtain the best possible fit.



CHECKING FOLLOWER SIDE MOTION



CHECKING FREEDOM OF FOLLOWER TRAVEL



BURNISHING ROUGH SPOTS

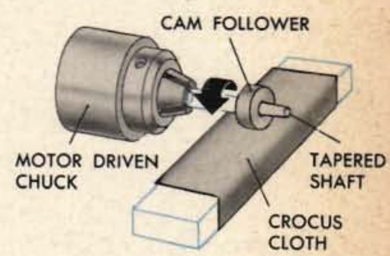
Fitting a new follower

Use a fine oilstone to smooth burred or rough edges of the follower. Remove any extremely sharp edges, but leave them square. It is very important not to round or chamfer the edges.

Polish the stud to fit the hole in the follower. The follower should turn smoothly on the stud without lost motion.

Fit the follower to the widest part of the groove. To reduce the width of the follower, polish it with crocus cloth. Mount it on a slightly tapered shaft held in a slow-speed motor-driven chuck. As the follower turns, polish it against crocus cloth wrapped around a metal block. Try the follower in the groove frequently until it just fits the widest part without lost motion.

Polish down all other parts of the groove to fit the follower, using crocus cloth wrapped around a metal bar. Continue polishing only until the follower will move freely throughout its length without lost motion. Thoroughly clean both the follower and the groove and lubricate them. Run the roller back and forth in the groove by hand until it will slide through its full travel when the cam is tilted at an angle of 45°.

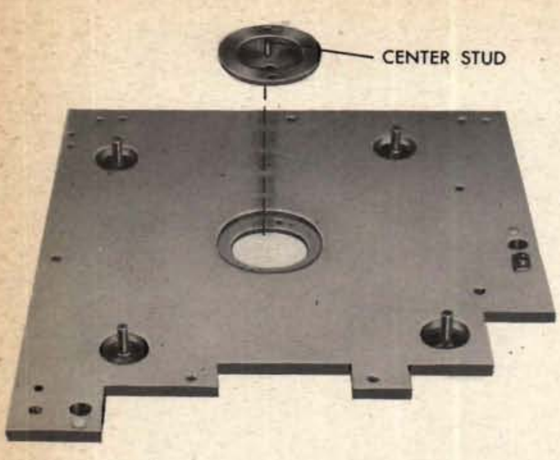


POLISHING THE FOLLOWER

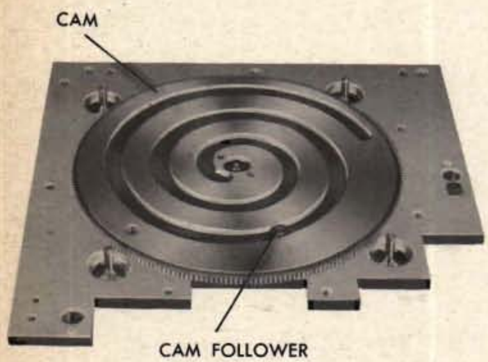
POLISHING TIGHT OR ROUGH SPOTS

Reassembling the unit

Wash and dry all the parts, and lubricate each part as it is replaced. Use a little grease on all slots, grooves, slide blocks, pivot studs, rack guides, guide rails, and the carriage block. Use light machine oil in the bearings and rollers.

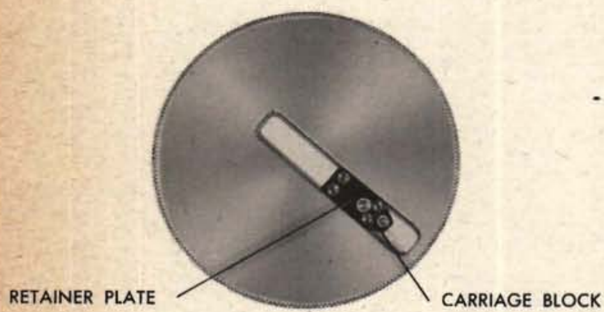


1 Replace the center stud.



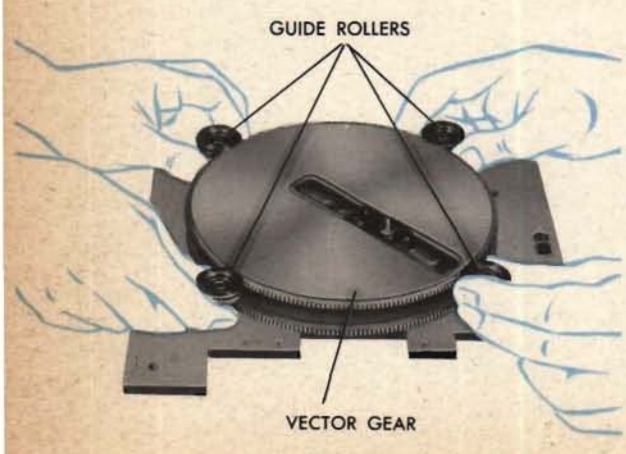
2 Replace the cam on its stud.

3 Place the cam follower in the cam groove.



4 Place the carriage block in the vector gear slot.

5 Fasten the retainer plate to the carriage block and stake metal from the screws into the indentations in the hardened plate.



6 Position the four rollers on the outside of the vector gear and place all four rollers on their studs. This job requires two men to avoid cocking or binding the vector gear.

7 Replace the snap rings on the roller studs.

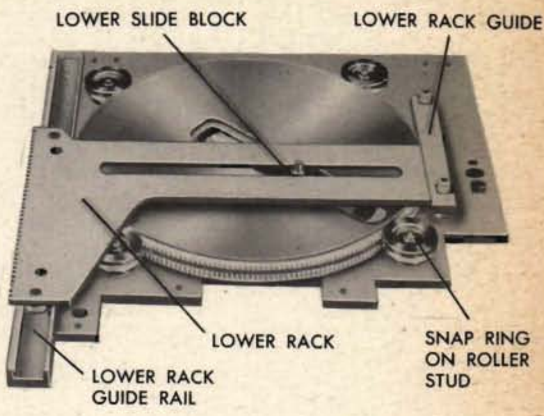
8 Replace the lower rack guide and guide rail.

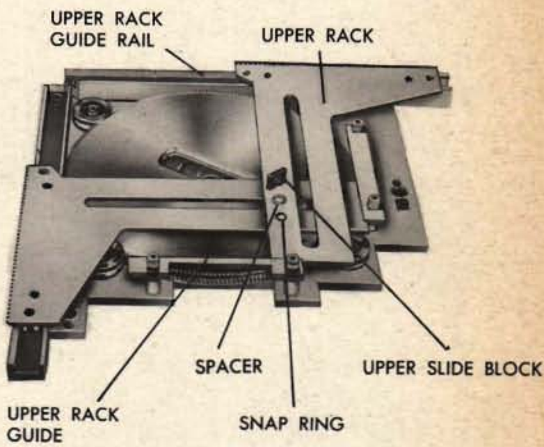
9 Place the lower slide block on the pivot stud.

10 Replace the upper-rack guide rail and rack guide.

11 Place the upper slide block on the pivot stud.

12 Replace the spacer and snap ring on the pivot stud.





Bench checking the unit

1 Check the assembly of the unit against the assembly drawing.

2 Check that the carriage block pivot stud may be brought to a zero point where there is no motion of the racks when the vector gear and cam are turned together. The maximum allowable rack movement at the zero point is shown on the assembly drawing.

3 With the cam follower at the outer limit of the cam groove, turn the vector gear through its full travel. The racks should move freely and smoothly through their full travel without excessive lost motion.

4 Using an indicator, check to be sure that the slots in the racks have been exactly squared.

5 Using an indicator, check that the cam gear and vector gear are concentric on their pivots. The assembly drawing gives the allowable variation of indicator readings.

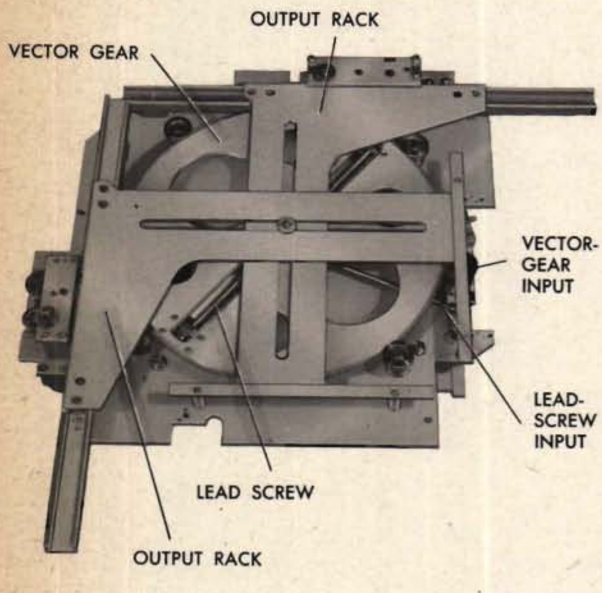
6 Check that all the eccentric roller studs have been doweled and that their nuts have been staked.

7 Check that lost motion between racks and rails is within the limits shown on the assembly drawing.

THE SCREW TYPE COMPONENT SOLVER

A screw type component solver either shares a plate with gearing groups and other units or is mounted on a separate base plate which is fastened to a larger plate. The inputs go to the lead screw and the vector gear. The outputs come from the two racks.

If the unit must be removed for repair, consult the instrument OP for instructions.



Typical symptoms

If a test analysis and a unit check test indicate that a screw type component solver is not operating normally, look for one or more of the following typical symptoms:

JAMMING: The lead screw, the vector gear, or one or both of the racks cannot be moved by hand.

STICKING: The vector gear or the racks move sluggishly or resist moving past certain points.

EXCESSIVE LOST MOTION: Too much play exists between a rack and rail, between the carriage block and lead screw, or between the carriage block and its slot; or the vector gear has too much side play. The lead screw may have too much end play between its hangers.

SLIPPING: Moving the lead-screw input or the vector gear results in only intermittent movement, or in no movement of the output racks.

Locating the cause

Lead screw: jamming or sticking

The lead screw may jam or stick because of a bent lead screw, dirty or damaged lead screw threads, a damaged slot in the vector gear or trouble in the shaft lines within the unit.

If the carriage is jammed at either end of the lead screw, try to move it out of its position by turning the lead-screw input gear. This type of jamming is usually caused by an incorrect limit-stop adjustment in the lead-screw input shaft line. The instrument OP gives directions for adjusting this limit stop.

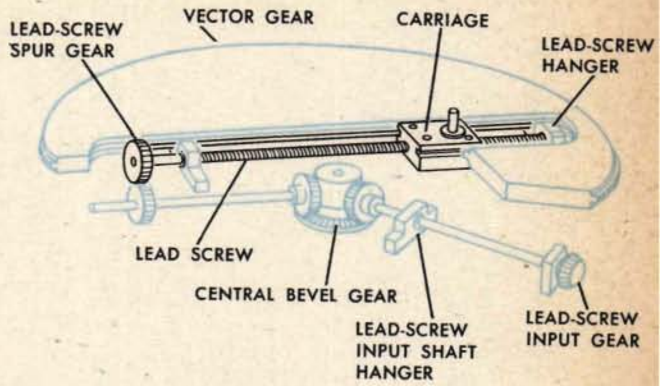
If the carriage jams or sticks within its normal travel, turn the lead-screw spur gear and watch the movement of the carriage. If it always jams or sticks at one place on the lead screw, inspect the screw threads for dirt or damage. Embedded particles may be removed or slightly damaged threads repaired without disassembly. To repair a badly damaged or bent screw, the unit should be disassembled.

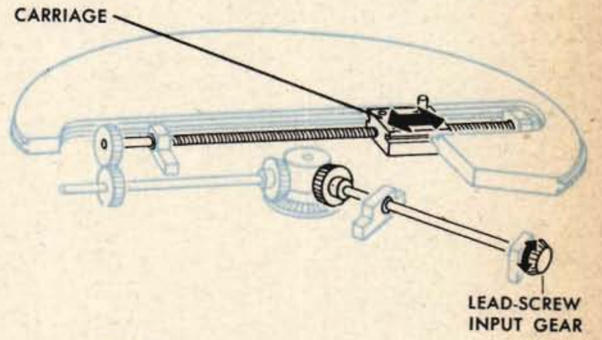
If the lead screw is undamaged, examine the guides in the vector slot for damage. Remove any high spots on the carriage guides by polishing with crocus cloth wrapped around a steel block.

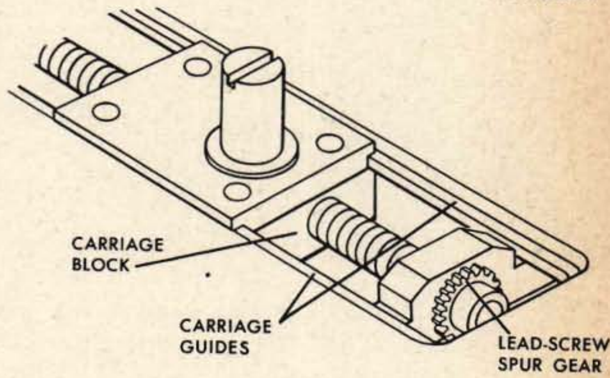
A badly damaged or bent lead screw may cause the block to stick throughout its travel. It is necessary to disassemble the unit in order to repair or replace the lead screw.

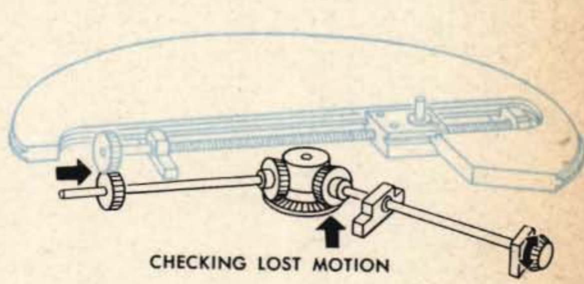
If the lead screw and carriage operate normally, the trouble may be caused by jammed gears, a bent shaft, or a defective bearing in the shaft line under the vector gear. Turn the lead-screw input gear back and forth to check for lost motion between the two spur gears and also between each of the bevel pinions and the central bevel gear.

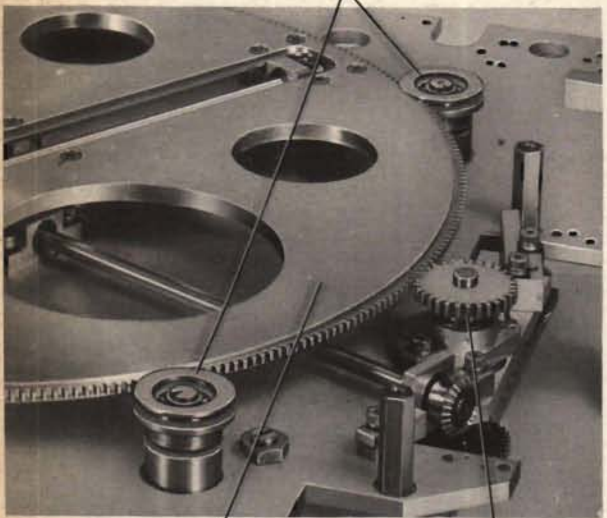
Tight bevel gears can usually be freed by repositioning the hangers. These hangers may have shifted because of an incorrectly adjusted limit stop in the vector-gear input shaft line. The instrument OP gives directions for adjusting this limit stop.





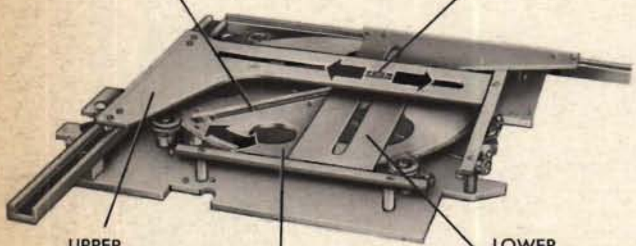




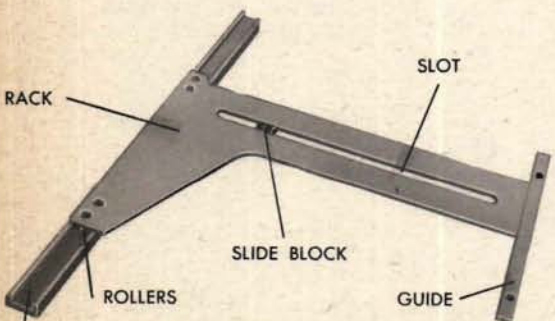


Vector gear: jamming or sticking

A vector gear may jam or stick because of dirty or damaged gear teeth, guide rollers, or guiding surfaces. Often the vector gear may be turned from its jammed position and the damage repaired without disassembling the unit. Dirt in the bearings of the guide rollers also may cause sticking. To clean the bearings, the rollers must be removed. This requires disassembling the unit.



The vector gear may not turn or may turn sluggishly because the slide blocks jam or stick on the pivot stud. The slide block in the upper rack may be removed without disassembling the entire unit.

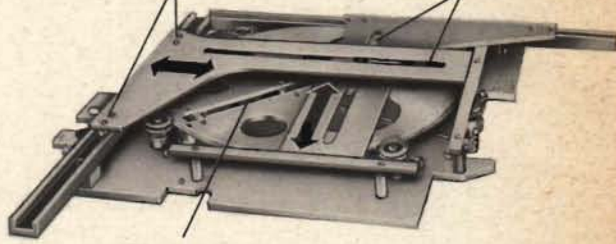


Racks: jamming or sticking

A rack may jam or stick because of a dirty or damaged rack guide, guide rail, rack roller, rack slot, slide block, or damaged gear teeth. Slight damage may be repaired and the parts cleaned and lubricated without disassembling the unit. Improper positioning of rollers may cause them to jam or stick in a rail, or may make too tight a mesh between the rack and pinion. Shake the rack to check lost motion between the rollers and the rail. Usually a slide block which sticks slightly in a rack slot may be restored to normal operation by cleaning and lubricating the sliding surfaces and running the parts back and forth to work them in smoothly.

Excessive lost motion

Excessive lost motion between the racks and their guide rails may be caused by damaged rollers or by loose or damaged roller studs.



Move the carriage to one end of its travel on the lead screw. Position the vector gear at various angles and shake the racks at each position. Lost motion between the racks and the lead screw may be caused by a worn slide block or slot, or by a worn carriage or vector slot. Such lost motion can be remedied only by replacing the worn parts. Disassembly of the unit is necessary.

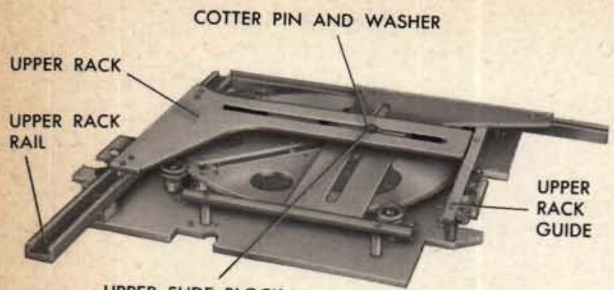
CHECKING THE VECTOR GEAR FOR SIDE MOTION

To check for excessive lost motion or side play of the vector gear, shake the gear. Any noticeable side play is caused by improper adjustment of the four guide rollers. To eliminate the excessive side play, the unit must be disassembled to reposition the roller studs. The side play must be removed without disturbing the centering of the vector gear. See page 268.

Slipping

If the racks do not move when the vector-gear or lead-screw input shaft is turned, the trouble may be caused by the fact that the lead screw threads are stripped, the pivot stud is broken, or the taper pin is missing from a gear hub. It will probably be necessary to disassemble the unit to make repairs.

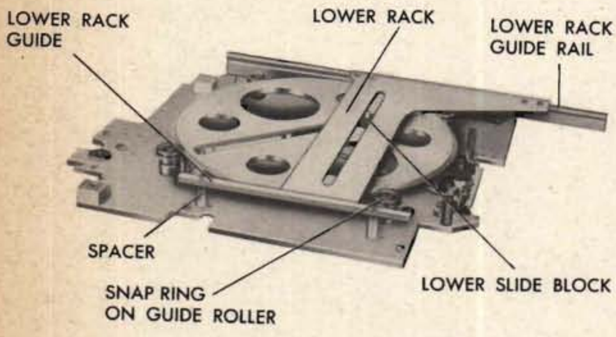
Disassembling the unit



1 Remove the cotter pin and washer from the stud.

2 Remove the screws holding the upper rack guide and rack rail, and lift off the rack, rack rail, and rack guide together.

3 Remove the upper slide block from the pivot stud. Keep the block with the rack.

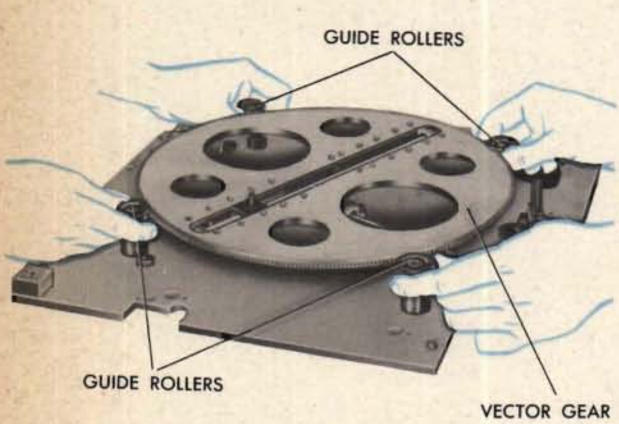


4 Remove the lower rack, rack rail, rack guide, and spacers.

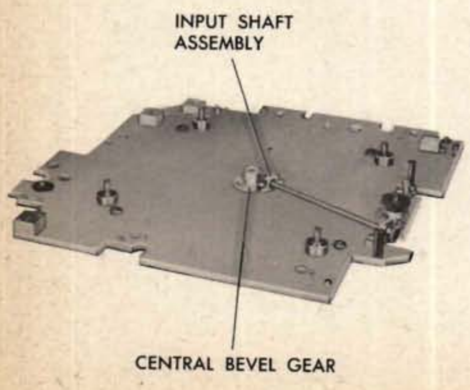
5 Remove the lower slide block.

6 Remove the snap rings from the four guide-roller studs.

7 To insure correct reassembly, mark each stud and its guide roller. Remove and tag each spacer with the identifying number of its stud.



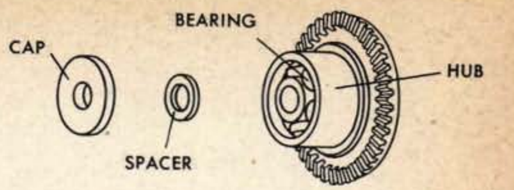
8 Being careful not to cock the gear, lift off the four guide rollers and the vector gear. This operation requires two men.



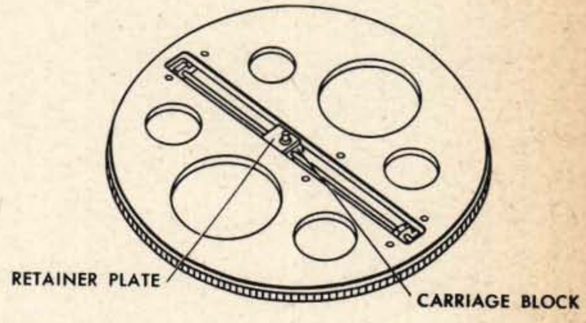
9 Remove the input shaft assembly from the plate by taking out its hanger screws.

10 Remove the flat-head screw and central bevel gear.

11 Remove the cap from the hub of the central bevel gear and lift out the spacer and bearings.



12 Take the retainer plate off the carriage block by removing the four socket-head screws.

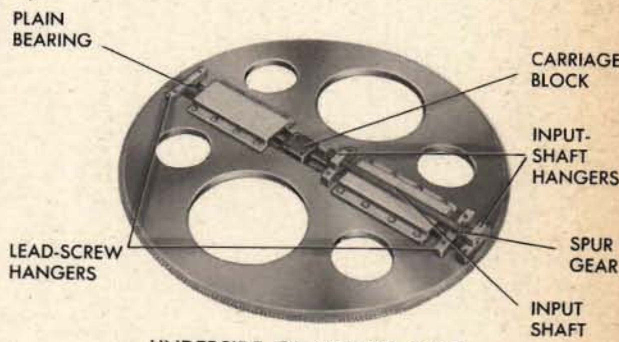


13 Remove the input shaft and hangers from the vector gear.

14 Remove the screws from the lead-screw hangers.

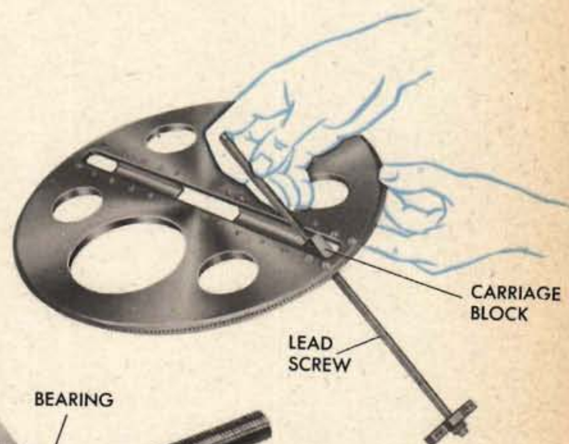
15 Remove the lead-screw hanger which acts as a plain bearing.

16 Turn the carriage block 90°.

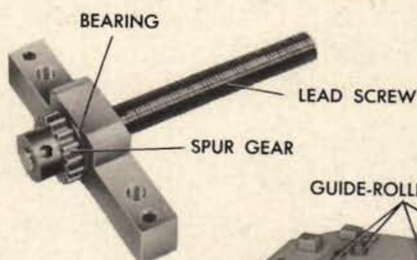


UNDERSIDE OF VECTOR GEAR

17 Slide the carriage block and the lead screw out of the vector gear.

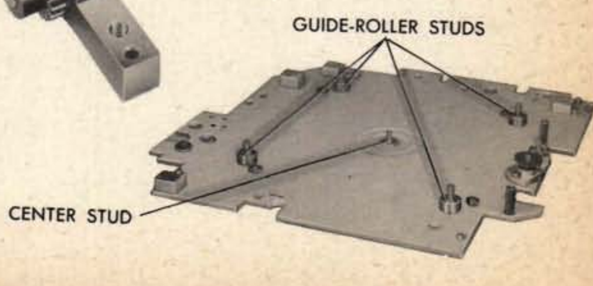


18 If the lead screw or lead-screw ball bearings must be replaced, unpin the spur gear, remove it with its spacer, and slide out the lead screw. Tap the bearings out of the hanger.

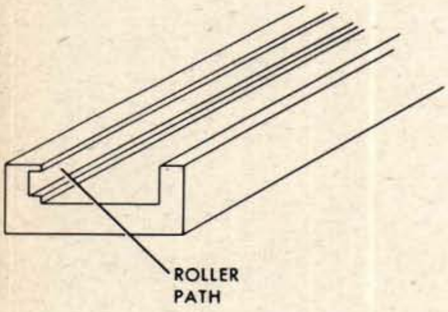


19 Do not remove the four guide-roller studs unless they must be readjusted for the purpose of recentering the vector gear or for removing excessive side play from the vector gear. If the studs are removed, mark the plate and tag the shims to insure correct reassembly. (Refer to step 7.)

20 Do not remove the center stud unless it must be replaced.

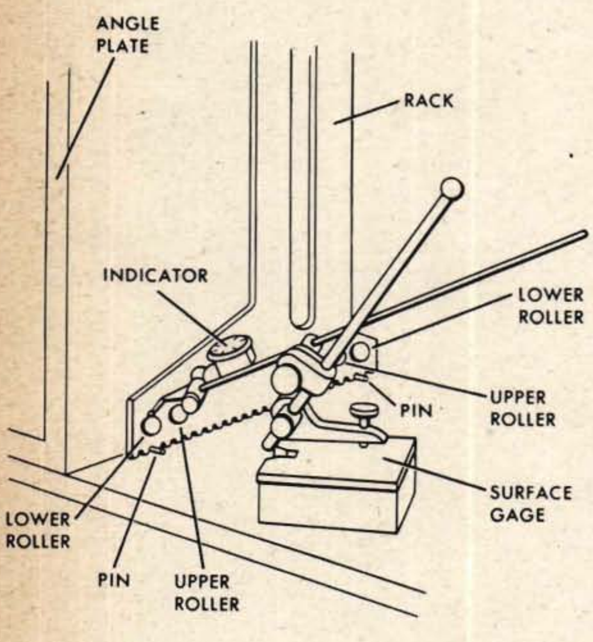


Repairing the parts



Repairing a rail

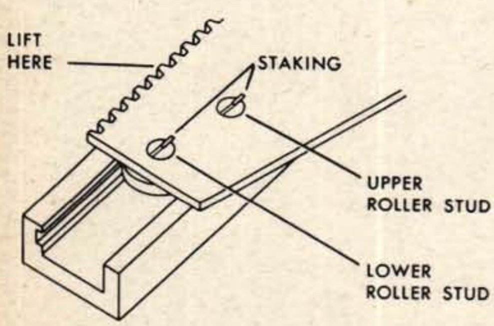
First use tissue to clean the roller path in the rail. Carefully remove any embedded foreign material. Then check the straightness of the roller path and, if necessary, polish rough or high spots with crocus cloth, trying the rack in the rail frequently until a good fit is obtained. After completing this work, wash the parts thoroughly with an approved solvent and lubricate them.



Repositioning rack rollers

The lower rollers establish the pitch line of the rack in relation to its meshing gear. These rollers affect the alignment of the rack slots as well as the mesh of the rack and the gear. Remove the rack and mount it against an angle plate on a surface plate. Support the rack under its teeth with two identical pins between 0.070 and 0.075 inch in diameter. Place one pin under each end of the rack. With a surface gage and a dial indicator, measure the height of the lower rollers. The heights of these rollers must agree with the assembly drawing and be within 0.0002 inch of each other. If these rollers are repositioned, the rack slots must be checked for squareness.

The upper rollers control the play between the rack and its rail. The play should not exceed 0.0005 inch. A strip of feeler gage material (0.001 inch) can be used as a "no go" gage to check the clearance between the roller and the roller path.



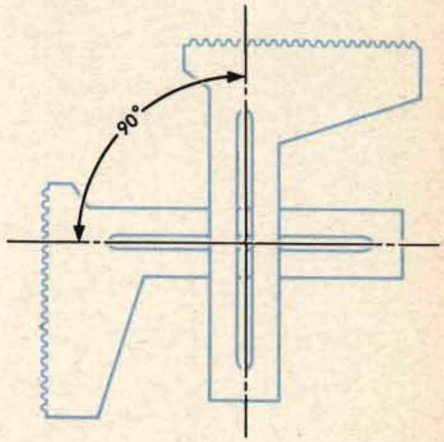
To position the rollers, turn the roller studs with a screw driver. Then stake a small amount of metal into the screw driver slots of the stud heads.

The rollers should be free enough in the rail for the rack to drop back of its own weight if it is raised slightly with one finger.

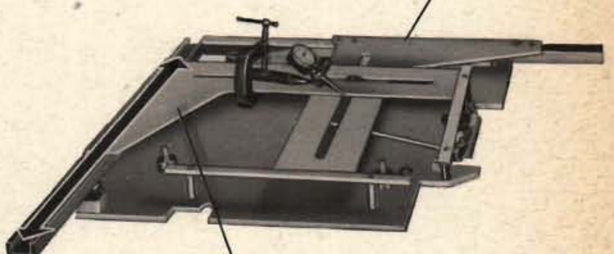
For an explanation of the proper method of removing and replacing a riveted stud, see pages 77-79.

Squaring the racks

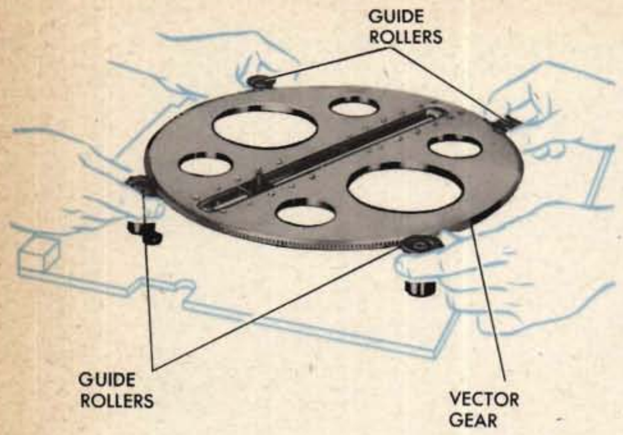
The slots in the upper and lower racks must be at right angles to each other.



Reassemble on the plate the two racks, their rails and guides. The vector gear should not be installed for this operation. Wedge the lower rack to prevent it from moving.



Mount a dial indicator firmly on the top rack with its point on one face of the lower rack slot. Move the upper rack through its full travel and observe the reading as the point of the indicator moves along the face of the slot in the lower rack. If the total reading exceeds 0.002 inch, check the setting of the lower rollers on the lower rack as instructed on page 266. It is advisable to check the lower rollers of the upper rack at the same time. Replace the two racks and repeat the check for squareness. If the indicator reading still exceeds 0.002 inch, reposition one of the rails. To do this, first drive the dowels out of the rail. Then replace the rail and its rack and repeat the check for squareness. If the indicator reading is still excessive, loosen the screws holding the rail, and move the rail within the clearance of its screw holes until a reading of 0.002 inch or less is obtained. Then tighten the screws and redowel the rail with oversize dowels.

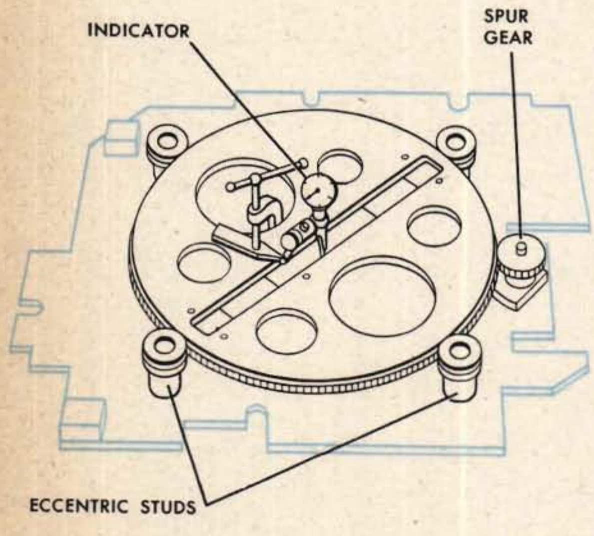


Positioning the vector gear

Centering the vector gear about the center stud and controlling the side play of the vector gear are accomplished by adjusting the eccentric studs which support the guide rollers.

First disassemble the unit as directed on pages 264 and 265. Remove the guide-roller studs, and drive out the dowels which hold them in place. Replace the studs, taking care to put them in their original holes. Then remount the vector gear, leaving off the lead screw and the central bevel gear.

Now clamp an indicator firmly on the vector gear with its point against the stud which supports the central bevel gear. Turn the vector gear one revolution, observing the variation in the indicator reading. This checks the vector gear and center stud for concentricity. If the total indicator reading exceeds 0.002 inch, adjust the guide-roller studs to center the vector gear. Turn the vector gear one revolution to check the concentricity again. At the same time, check that the vector gear turns freely with no more than 0.0005 inch side play. If the side play is excessive, adjust the studs accordingly, but recheck the concentricity after this adjustment is made.



INDICATOR POINT
TOUCHING CENTRAL BEVEL GEAR STUD

The vector gear may stick at one point and have excessive side play at another point because of damage to its guiding surfaces. Remove high spots or imbedded particles from the guiding surfaces by careful use of a scraper.

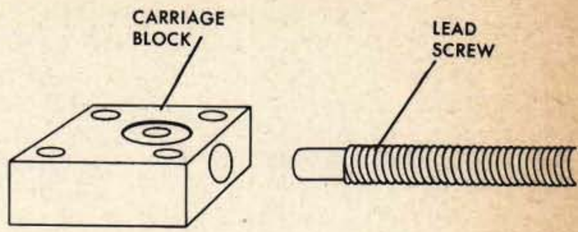
After the vector gear has been positioned satisfactorily, turn the unit over, stake the stud nuts and dowel the studs to the plate.

Adjusting the mesh between the vector gear and its spur gear

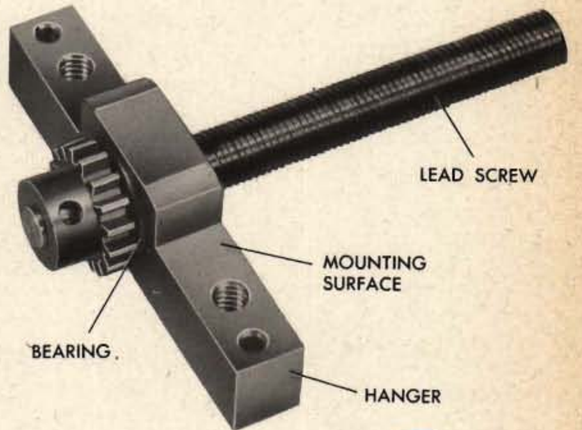
If there is excessive lost motion between the vector gear and the spur gear which drives it, the spur gear should be repositioned. *Never* move the vector gear to reduce such lost motion. Doing so will disturb the concentricity of the vector gear about the center stud.

Replacing a lead screw or a carriage block

Before starting a lead screw into a carriage block, make sure that no dirt or chips have been picked up in handling the parts. Then, using an approved lubricant, lubricate both parts and start the lead screw carefully into the unthreaded end of the hole in the block. Run the whole length of the screw through the block to see that it travels smoothly.



Mount the lead screw in the hanger containing two bearings. Pin the spur gear to the shaft, using a suitable spacer between the gear and the bearing to control the end shake. The end shake of the lead screw in the bearings must be kept at a minimum, because the total end shake of the lead screw and carriage block should not exceed 0.0015 inch after mounting on the vector gear.



Mount the lead screw and carriage block in the vector-gear slot.

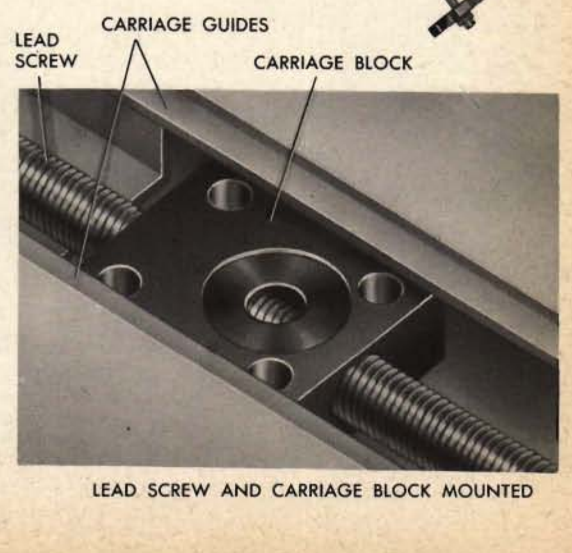
MOUNTING THE LEAD SCREW AND CARRIAGE BLOCK ON THE VECTOR GEAR

Turn the lead screw to move the carriage block the entire length of the slot. The block should slide freely, just touching the under sides of the carriage guides.

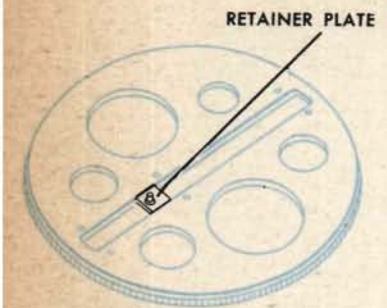
If the block does not touch both guides at the same time, one or both of the bearings supporting the ends of the lead screw is too high. Reduce the height of a bearing by scraping the mounting surface of the hanger; otherwise the lead screw will bind when the retainer plate is attached to the carriage block.

If, with each turn of the screw, the block alternately presses against and moves away from the guides, the screw probably is bent. A bent lead screw should be replaced, but if no spare is available and the lead screw is made of aluminum, it can sometimes be straightened by hand sufficiently to be used temporarily.

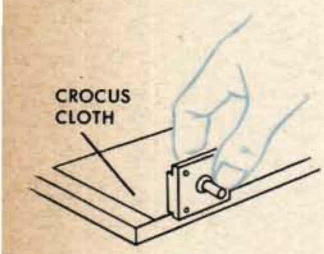
If the block fits tightly against the guides throughout its travel and causes the lead screw to bind, particularly when the block is near the ends of the lead screw, remove the block and polish the top of it on crocus cloth laid flat on a surface plate until the proper fit is obtained.



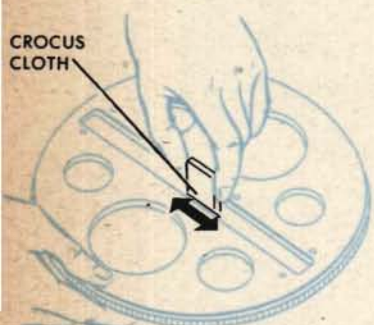
LEAD SCREW AND CARRIAGE BLOCK MOUNTED



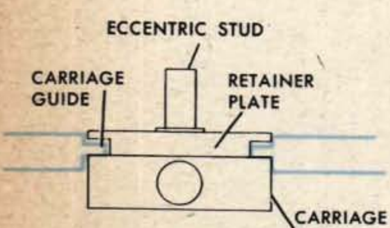
TESTING THE RETAINER PLATE ON THE GUIDES



POLISHING THE SIDES OF A RETAINER PLATE



POLISHING INNER FACES OF CARRIAGE GUIDES



CARRIAGE

Fitting a new retainer plate

In fitting a new retainer plate, first rivet a new pivot stud in place. (Follow the directions for riveting and positioning eccentric roller studs on page 78.) Then use a fine oilstone to remove any sharp "feather" edges. Stone sparingly, as it is important not to round or chamfer the edges.

With the lead screw and the carriage block removed, try the retainer on the carriage guides. If necessary, polish the sides of the retainer on crocus cloth until it fits without lost motion in the widest part of the space between the carriage guides. Remove equal amounts from each side so that the stud hole remains centered. During this operation do not remove material from any surface of the retainer except the sides which fit between the guides. Measure the retainer occasionally with a micrometer to be certain that the sides are parallel.

Polish the inner faces of the carriage guides with crocus cloth backed up by a steel bar until the retainer can be moved freely through the full length of the vector gear slot. Keep the sides square and flat. Clean the guides and the retainer thoroughly each time before trying them together. Apply a little approved lubricant and move the retainer back and forth by hand until it travels smoothly from one end to the other.

Mount the retainer on the carriage block in the vector gear slot. Tighten each of the four screws a little at a time. Each time the screws are tightened, slide the carriage back and forth on the guides.

If the slots in the carriage are too narrow, the carriage will clamp tightly on the guides when the screws are tightened. Remove the retainer and polish the lips which ride on the upper faces of the guides until the carriage can be moved over the thinnest portion of the guides. Then, if necessary, polish the upper faces of the guides to fit the slots in the carriage.

If the slots in the carriage are too wide, the carriage will fit loosely. (The clearance should be between 0.0005 and 0.0011 inch.) Polish the bottom of the retainer to reduce the width of the slots.

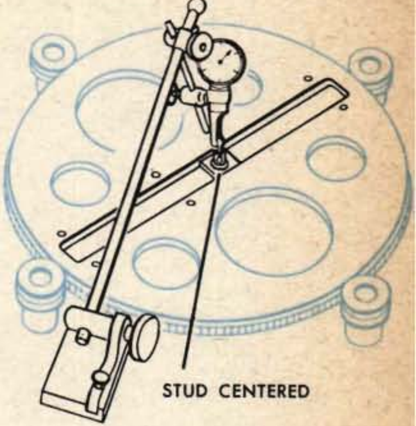
After a retainer has been fitted, clean and lubricate the lead screw, the carriage, and the carriage guides with approved solvents and lubricants. Mount the lead screw and the carriage on the vector gear. Turn the lead screw, and check the freedom of the carriage as it travels from one end of the slot to the other. If it drags, probably the lead screw is pulling the carriage against one guide. Remove the lead screw and drive the dowels out of the vector gear. Remount the lead screw and position the hangers so that the carriage moves smoothly through its entire travel. Tighten the screws; redowel the hangers to the vector gear with oversize dowels; lubricate the parts again, and make a final check for smoothness of travel.

Centering the pivot stud

Position the carriage so that the eccentric pivot stud lies directly above the central bevel gear and hold it in this position by wedging the spur gear at the end of the lead screw.

Mount a surface gage and dial indicator as shown in the accompanying illustration. Turn the vector gear one revolution, observing any changes in the indicator reading. If the total changes in the reading exceed 0.002 inch, compensate first by repositioning the carriage and then by adjusting the eccentric stud.

Remove the retainer plate and stake the stud in place. Tap lightly, supporting the retainer plate directly under the staking tool. A heavy blow may warp the retainer.

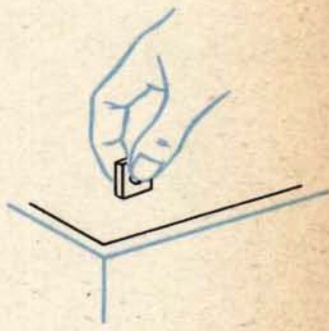


Fitting a new slide block

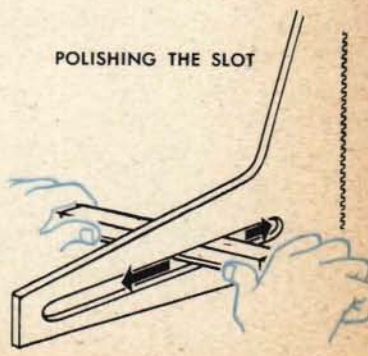
Use a fine oilstone to smooth burred and rough edges of the slide block. Remove any extremely sharp edges but leave them square. It is very important not to round or chamfer the edges.

To reduce the width of the block, polish the sides on a piece of crocus cloth placed on a flat surface, using long, even strokes while holding the block square. Be sure to remove equal amounts from each side, so that the hole remains perfectly centered. Measure the block occasionally with a micrometer to be certain that the sides are parallel.

Polish the block until it fits closely in the widest portion of the slot. Polish the rest of the slot to fit the block, using crocus cloth wrapped once around a steel bar. Be sure to keep the slot sides square and flat. Before trying the block in the slot, thoroughly wash, dry and lubricate them both. The fit is correct when the block can be moved the full length of the slot. Move the block back and forth by hand until it travels smoothly from one end to the other. Finally, wash the slot and block again, and lubricate the slot.



POLISHING THE SLIDE BLOCK



POLISHING THE SLOT

Repairing the shaft lines

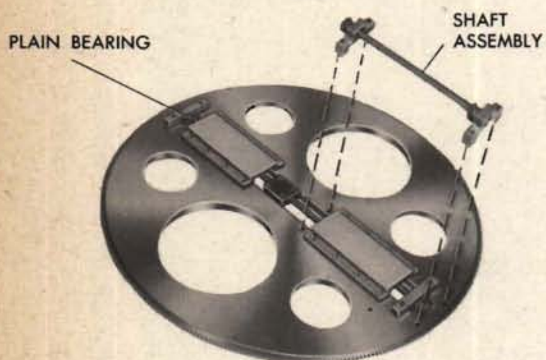
For a detailed explanation of checking bearings, straightening shafts, and removing end play and lost motion from shaft assemblies, see *Basic Repair Operations*.

Reassembling the unit

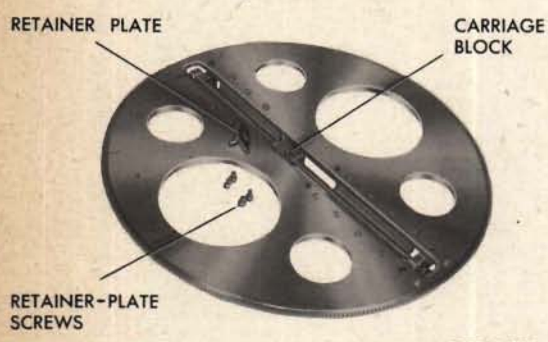
Wash all the parts with an approved solvent, and then dry them. Lubricate each part as it is replaced.

1 First making certain that the lead screw was started into the unthreaded end of the hole in the carriage block, place the lead screw in the vector-gear slot with the block in the position shown.

2 Replace the hanger which acts as a plain bearing, and secure both hangers to the vector gear.

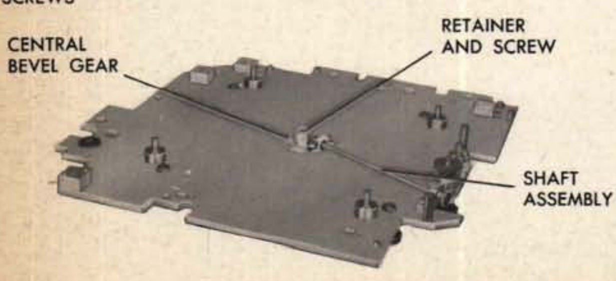


3 Replace the shaft assembly on the vector gear.



4 Replace the retainer plate on the carriage block. (Check that the pivot stud is staked.)

5 Replace the bearings in the central bevel gear hub and mount the gear on its stud.



6 Replace the spacer and the cap on the stud, and hold them down with a flat-head screw.

7 Replace the shaft assembly on the plate.

8 Place the four rollers around the vector gear, and lower the rollers as shown, each one on its respective stud. Replace each spacer on its proper stud. (These parts should have been given identifying marks when disassembled.)

9 Secure the guide rollers on the studs with snap rings.

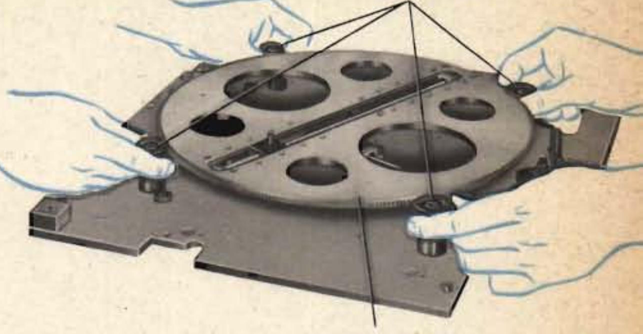
10 Put the lower slide block on the pivot stud.

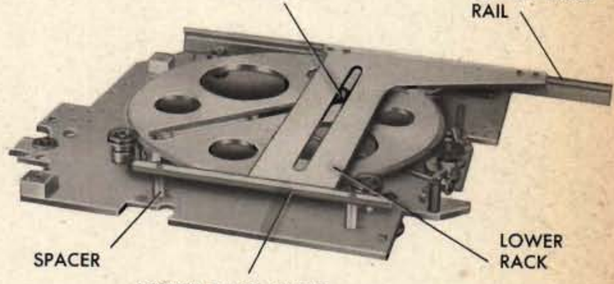
11 Put the lower rack, rail, and guide in place, with the lower slide block in the rack slot. Replace the spacers under the rack guide, and then secure both the guide and the rail to the plate.

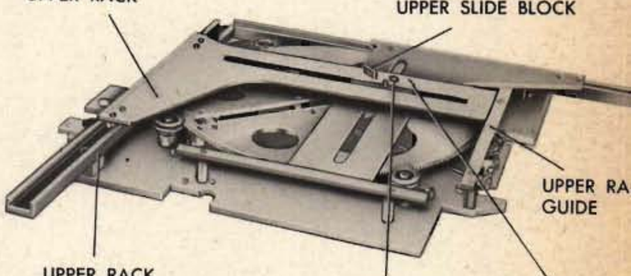
12 Put the upper slide block on the pivot stud.

13 Put the upper rack, rail, and guide in place, with the slide block in the rack slot. Secure the rack guide and rail to the plate.

14 Secure the slide blocks on the pivot stud with a washer and a cotter pin.







Bench checking the unit

1 Check the assembly of the unit against the assembly drawing.

2 To check for smoothness and for correct lost motion, move the racks through their full travel by turning the vector gear when the carriage is at one end of the lead screw. The bevel-gear hangers limit the rotation of the vector gear. Do not strike them.

3 Check that the pivot stud may be brought to a zero point where there is no motion of the racks when the vector gear is turned.

4 Check that the rotation of the vector gear is stopped only when the bevel-gear hangers touch. Make this test with the carriage at both ends of its travel.

5 Check that the carriage cannot be moved along the slot more than 0.0015 inch.

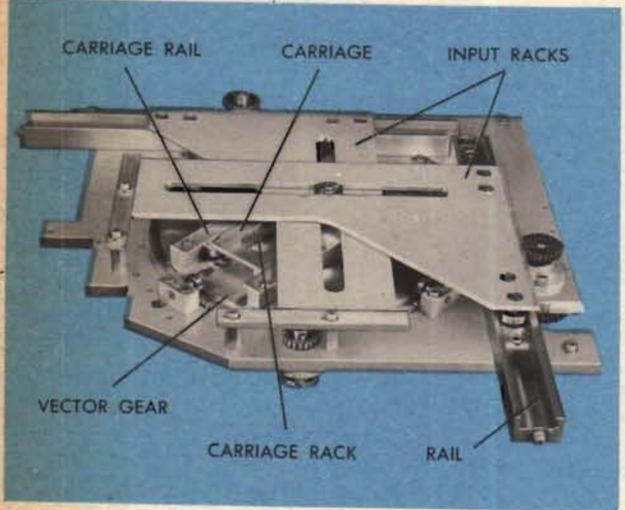
6 Check that the lead screw and the connected shaft lines turn freely throughout the travel of the carriage.

7 Check that the slots in the racks are at right angles to each other.

8 Check that the lost motion between the racks and their rails is no more than 0.002 inch.

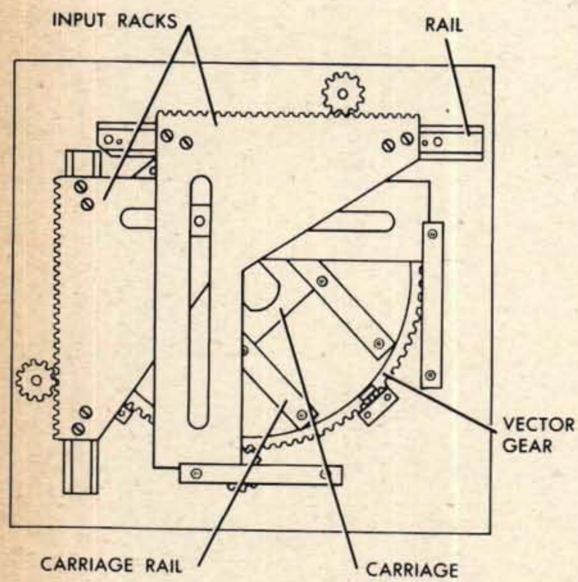
9 Check that the eccentric studs in the racks have been staked.

THE VECTOR SOLVER



A vector solver is usually mounted on a separate base plate with the input and output gears at the sides of the unit. The *inputs* are carried by the *two racks.* The *outputs* are carried by the *vector gear* and the *carriage rack.*

In order to remove a vector solver, other units and gearing groups often must be removed first. For this reason, the exact source of the trouble should be located before removal is considered. If the unit must be removed for repair, consult the instrument OP for instructions.



Typical symptoms

If a test analysis and unit check test indicate that a vector solver is not operating normally, look for one or more of the following typical symptoms:

JAMMING: The carriage, the vector gear, or one or both of the racks cannot be moved by hand.

STICKING: The carriage or one or both racks moves sluggishly, or resists moving past certain points.

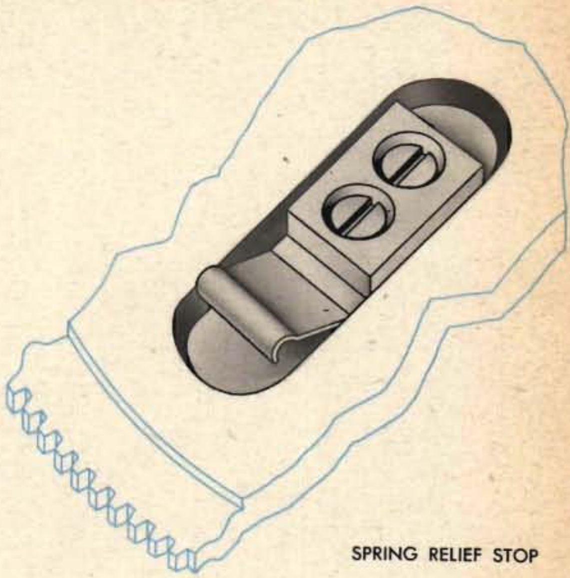
EXCESSIVE LOST MOTION: Too much play exists between a rack and rail, the carriage and its rails, or the carriage rack and its meshing gear.

SLIPPING: Moving the input racks results in only intermittent movement or in no movement of the vector gear, or of the carriage rack or pinion.

Locating the cause

Carriage: jamming or sticking

The carriage may be jammed at the end of its travel by driving against its stop on the vector gear, breaking the stop, and overrunning it.



SPRING RELIEF STOP

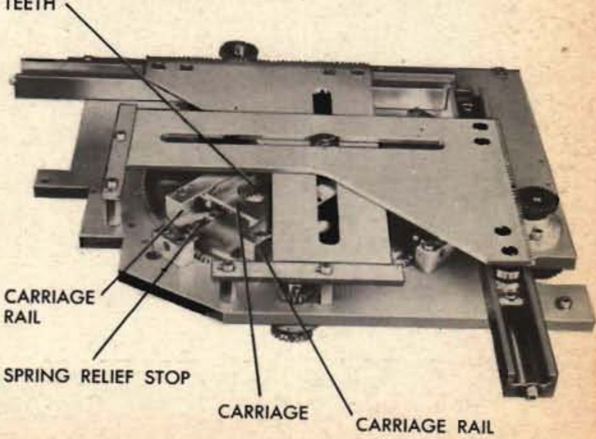
The carriage stop mounted on the vector gear is in the form of a spring relief in some instruments, while in others it is a positive type. Usually a carriage jammed on a spring relief stop may be pushed back into its normal travel range without disassembling the unit. A carriage jammed on a positive post stop can be freed only by disassembling the unit.

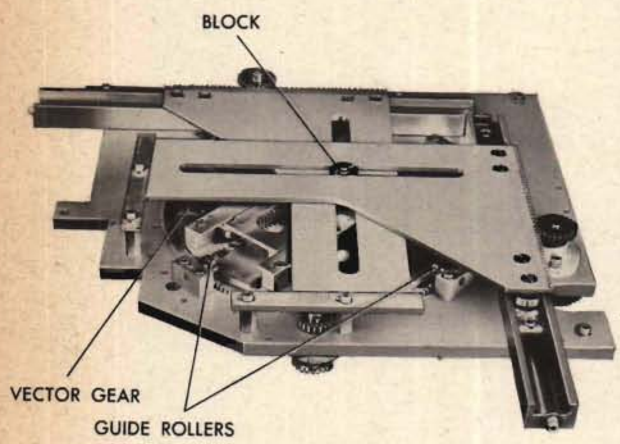
POSITIVE POST STOP

If the carriage jams or sticks within its normal travel, the trouble may be caused by damaged or dirty gear teeth or insufficiently lubricated carriage rails. A rack slide block frozen on the carriage pivot stud may also prevent movement of the carriage.

Try to free the carriage by pushing it along the rails. If the carriage can be moved, it is often possible to locate the cause of jamming and sticking and correct it without disassembling the unit. Cleaning and lubricating the rails will often eliminate sticking.

If the carriage cannot be moved, a rail, the carriage, or a rack slide block on the carriage pivot stud may be damaged, and the unit should be disassembled for repair.



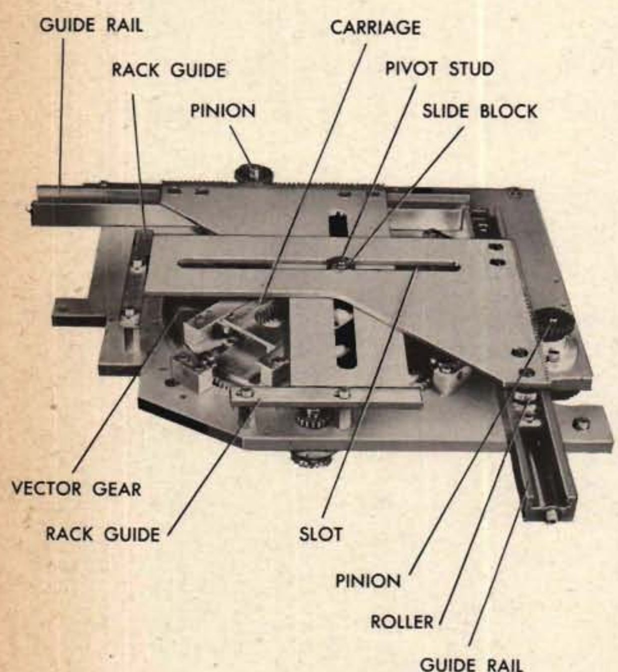


Vector gear: jamming or sticking

A vector gear may jam or stick because of damaged or dirty gear teeth, guide rollers, or vector-gear bearings. Dirt, burrs, or nicks in the gear teeth can sometimes be removed without disassembling the unit. If the guide rollers do not turn freely and the vector gear moves sluggishly, the guide roller assemblies should be removed and washed. On some units this can be done without disassembly.

The vector gear may not turn or may turn sluggishly because the slide blocks jam or stick on the pivot stud. Inspect these blocks for jamming or sticking. The block in the slot of the outside rack can be repaired without disassembling the entire unit.

Often the vector gear can be moved from its jammed position by hand and cleaned and lubricated without disassembling the unit. Turn the vector gear to inspect the teeth for dirt or damage.



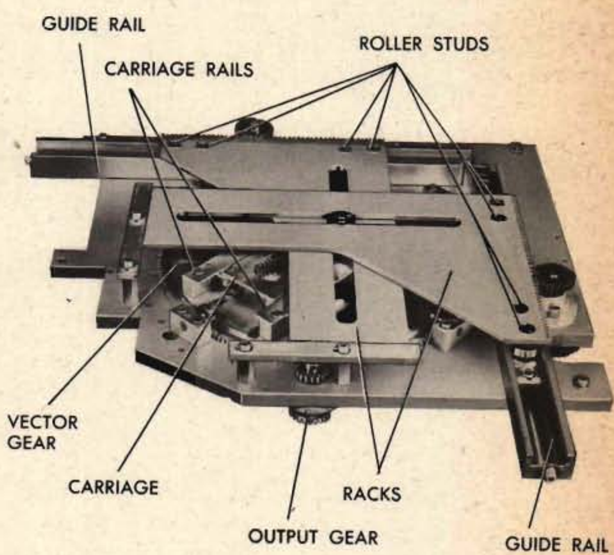
Racks: jamming or sticking

A rack may jam or stick because of a dirty or damaged rack guide, guide rail, rack roller, rack slot, slide block, or gear teeth. Slight damage can be repaired and the parts cleaned and lubricated without disassembling the unit. Improper positioning of rollers may cause them to jam or stick in a rail, or make too tight a mesh between the rack and pinion. Shake the rack to check lost motion between the rollers and the rail. Usually a block which sticks slightly in a rack slot can be restored to normal operation by cleaning and lubricating the sliding surfaces and running the parts back and forth to work them in smoothly. Disassemble the unit for repair only if it sticks enough to cause serious errors in the operation of the instrument.

If neither rack can be moved and the cause is not found in the parts in contact with the racks, the trouble may be caused by a jammed carriage or vector gear.

Excessive lost motion

Excessive lost motion of the racks may be caused by worn parts or a loose or bent roller stud. If lost motion is not reduced, it may allow a rack to cock and cause it to jam or stick later. Shake each rack to check that the lost motion does not exceed the limits given on the assembly drawing. If it does, the racks should be removed to reposition the rollers.

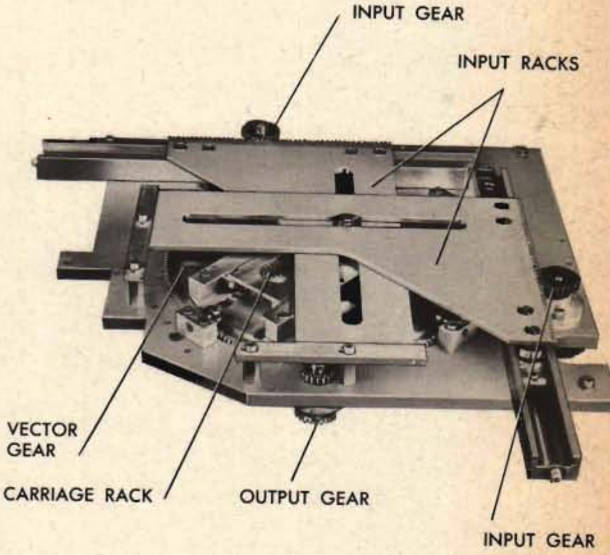


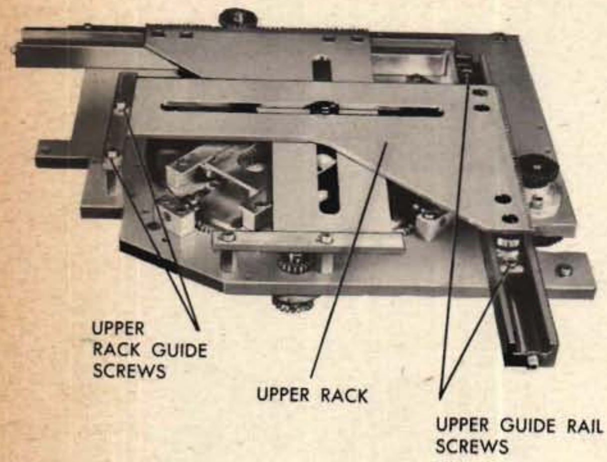
Place the carriage and the vector gear at various positions within their travel and shake the racks at each position. Lost motion between the racks and the carriage may be caused by worn slide blocks and rack slots. Such lost motion can be remedied only by disassembling the unit and replacing both the blocks and the racks.

Excessive lost motion between the carriage and its rails, or between the carriage and the output gear may result from wear or from improperly positioned guide rails. Lost motion of the carriage may be checked by shaking the carriage. Refer to the assembly drawing for the allowable maximum.

Slipping

If moving the input racks results in only intermittent movement of the vector gear or of the carriage rack or pinion, the trouble may be caused by stripped rack teeth, a broken pivot stud, or by sheared pins in either an input or output gear. Replace any rack which has stripped teeth. To inspect for a loose pivot stud, move the carriage and turn the vector gear to move the racks through their full travel. If the racks do not move smoothly, the pivot stud may have loosened or sheared, and the unit should be disassembled for repair. To check for a sheared pin, hold the gear and try to turn the shaft. If the gear does not turn with the shaft, repin the gear.





Disassembling the unit

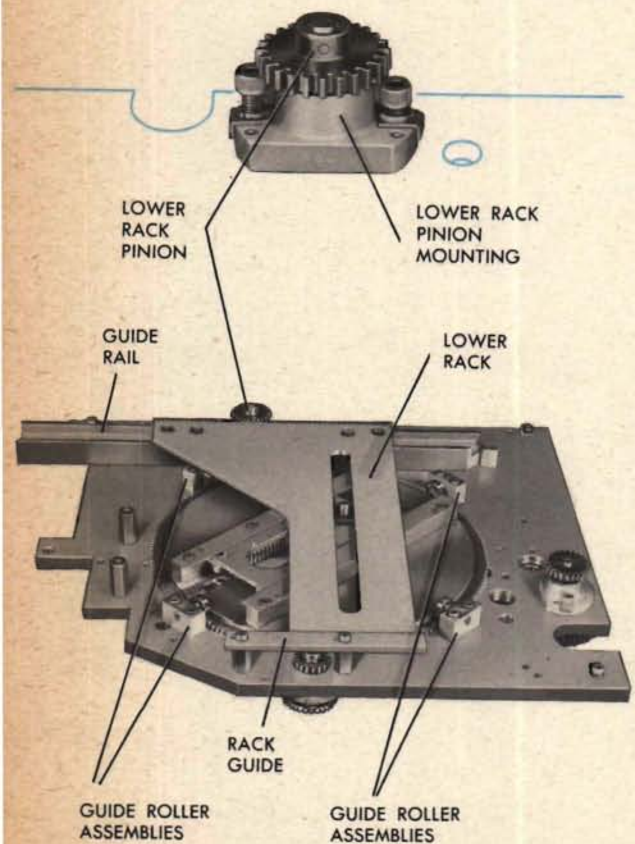
1 Remove the cotter pin and spacer from the pivot stud.

2 Remove the screws holding the upper rack guide.

3 Remove the screws holding the upper guide rail.

4 Lift off the upper rack, rack guide, and guide rail together.

5 Remove the upper slide block and keep it with its rack. Save the spacers.



6 Loosen the mounting of the pinion gear meshing with the lower rack.

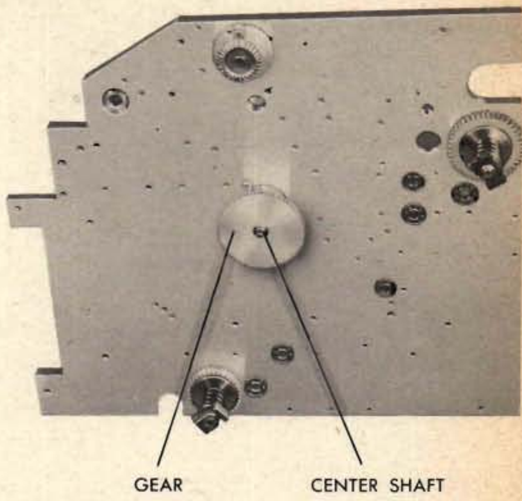
7 Remove the lower rack, rack guide, and guide rail together.

8 Remove the lower slide block and keep it with its rack. Save the spacers.

9 Remove the carriage from the vector gear.

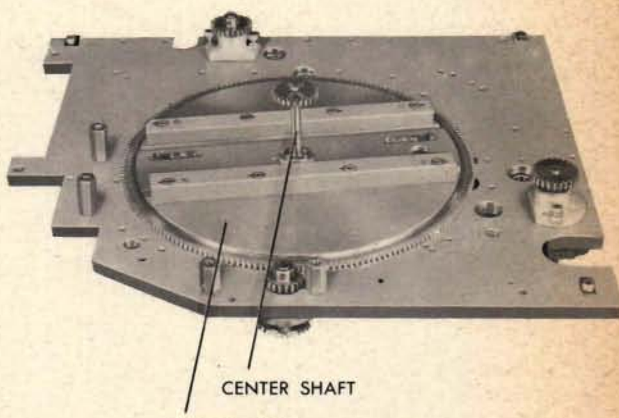
10 Remove the four guide roller assemblies.

11 Unpin the gear on the underside of the conter shaft.

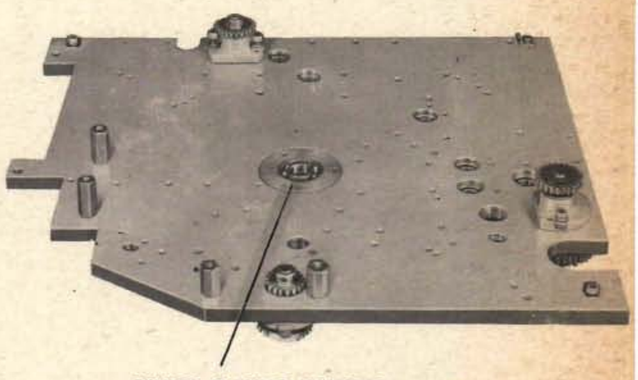


12 Remove the center shaft.

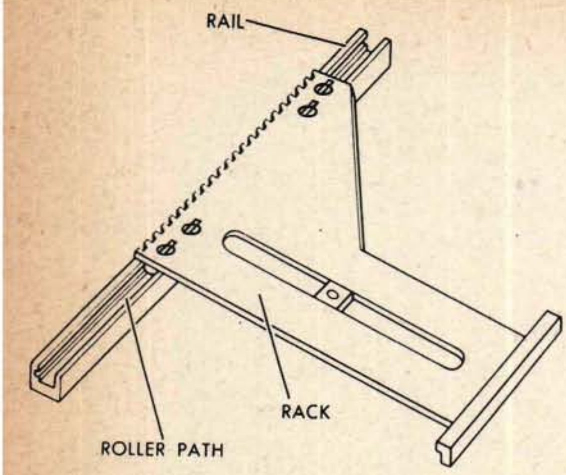
13 Lift off the vector gear.



14 Remove the center bearing housing. Do not remove the rollers or the rack from the carriage unless these parts require replacement. The carriage rollers cannot be adjusted.

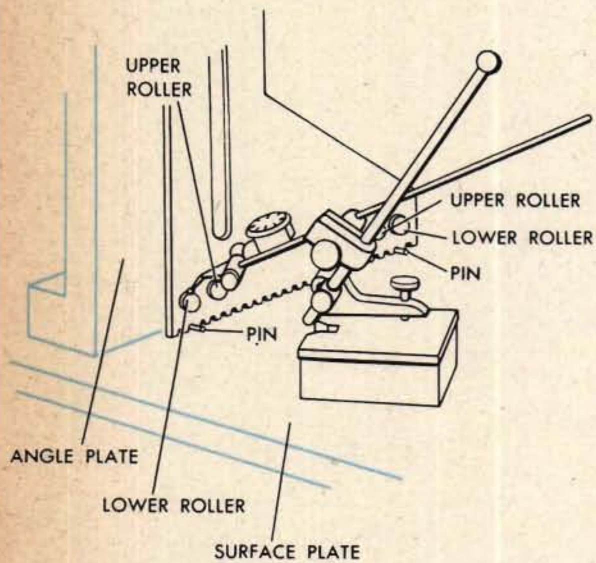


Repairing the parts



Repairing a rail

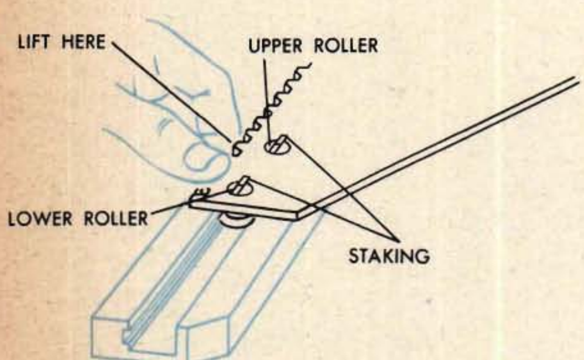
First use tissue to clean the roller path in the rail. Carefully remove any embedded foreign material. Then check the straightness of the roller path, and if necessary polish rough or high spots, trying the rack in the rail frequently until a good fit is obtained. After completing this work, wash the parts thoroughly with an approved solvent and lubricate.



Adjusting the rollers

The lower rollers establish the pitch line of the rack in relation to its meshing gear. These rollers affect the alignment of the rack slots as well as the mesh of the rack and the gear. Remove the rack and mount it against an angle plate on a surface plate. Support the rack under the teeth, using two identical pins between 0.070 inch and 0.075 inch in diameter. Place a pin at each end of the rack.

With a surface gage and a dial indicator, measure the height of the lower rollers. The heights of these rollers must agree with the assembly drawing and be within 0.0002 inch of each other. If these rollers are repositioned, the rack slots must be checked for squareness.



The upper rollers control the play between the rack and the rail. If the play exceeds 0.0005 inch, turn the roller studs with a screw driver. A strip of feeler gage material (0.001 inch) can be used to check the clearance between the roller and the roller path. After positioning the rollers, stake a small amount of metal into the screw driver slots of the stud heads. The rollers should be free enough in the rail for the rack to drop back of its own weight if it is raised slightly with one finger.

For an explanation of removing and replacing a riveted stud, see pages 77-79.

Squaring the racks

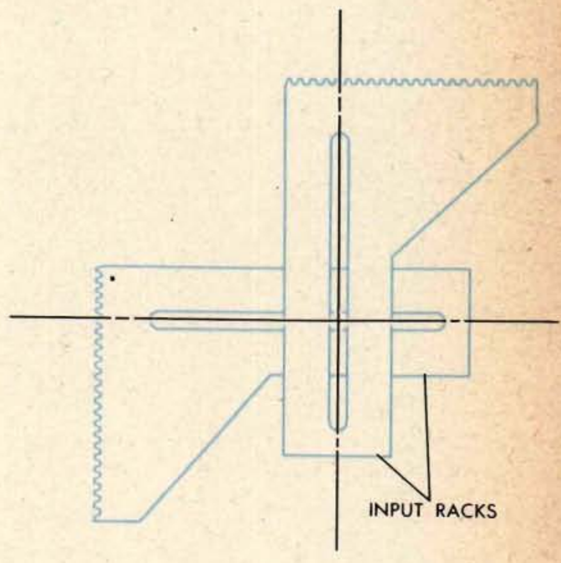
The slots in the two input racks must be at right angles to each other. Mount the two racks, their rails, and guides on the plate. The vector gear and other parts should not be reinstalled.

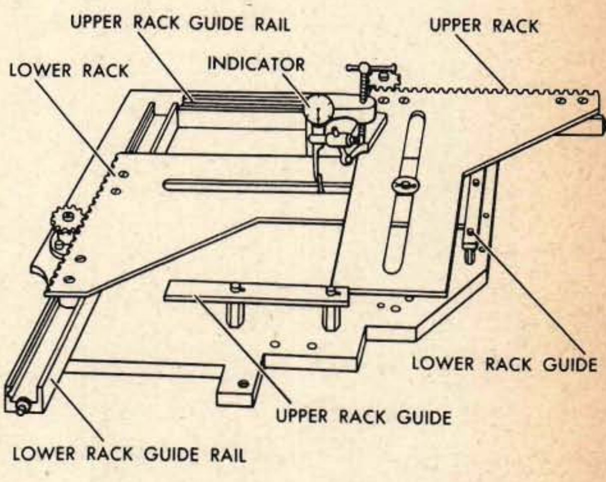
Squareness of the racks must be tested with the indicator mounted first on the upper rack and then on the lower rack to make certain that all the necessary conditions have been established.

Wedge the lower rack. Then mount a dial indicator firmly on the top rack with the point of the indicator on one face of the slot in the lower rack. Move the top rack through its full travel. Observe the reading of the dial as the indicator point moves along the face of the lower rack slot.

If the total indicator reading exceeds 0.001 inch, check the setting of the lower rollers in the lower rack, as explained on the preceding page. It is advisable to check the lower rollers of the upper rack at the same time. Remount the racks and repeat the check for squareness. If the indicator reading still exceeds 0.001 inch, reposition the rail which holds the upper rack. To do this, remove the dowels from the rail. Replace the rail and its rack and repeat the check for squareness. If the indicator reading is still excessive, loosen the screws holding the rail, and move the rail within the clearance of its screw holes until a reading of 0.001 inch or less is obtained. Then tighten the screws and redowel the rail with oversize dowels.

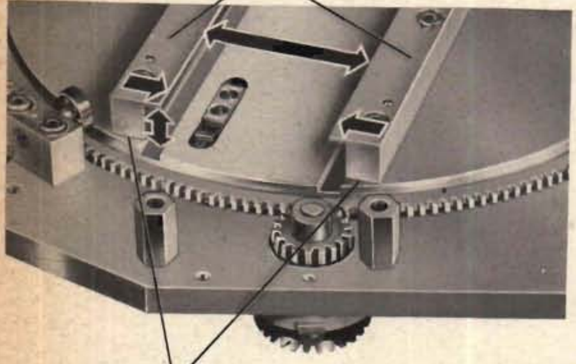
If the total reading is within the proper tolerance when the indicator is mounted on the upper rack, the indicator must be mounted on the lower rack and the test repeated as explained for the upper rack.





Adjusting the carriage

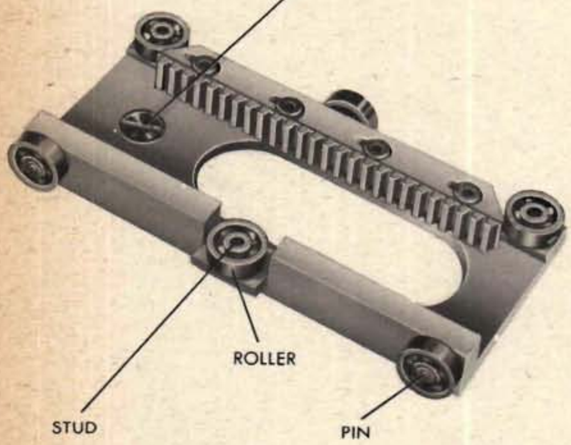
Excessive up-and-down motion of the carriage between the rail and the vector gear can be reduced by removing the rails and polishing their under surfaces. Be careful to polish the rails equally so that the under sides of both rail flanges remain parallel with the vector gear surface and equidistant from it.



Excessive side motion of the carriage between the rails can be eliminated by repositioning the rails. Remove the rail dowels and tap both rails equal distances toward the center. It is very important to move the rails *equal* distances because the eccentric pivot stud in the carriage must be centered again after this operation. After repositioning the rails, check the mesh of the carriage rack and the pinion. If the mesh is not satisfactory the rack must be repositioned.

Replacing carriage rollers

Carriage rollers are not adjustable because they are mounted on concentric studs. When a damaged carriage roller is replaced, a new stud should always be used. These studs fit into blind holes in the carriage and are held in position by straight pins.



UNDER SIDE OF CARRIAGE

To remove a stud, drive out the straight pin and carefully pry up the roller and stud. Rivet the new stud to the new roller and insert the stud in the carriage hole. For a detailed explanation of riveting and removing studs, refer to the explanation on page 76 .

Drill and ream the pin hole to fit a slightly oversize straight pin. Drive in the new straight pin and stake metal over *both* ends of the hole.

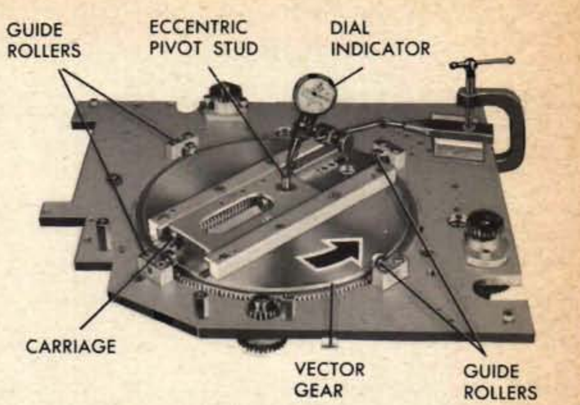
Centering the pivot stud

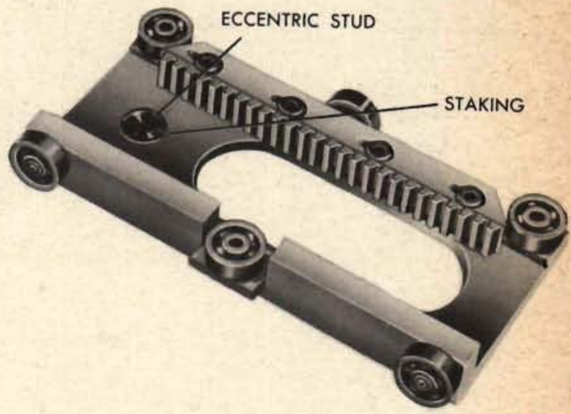
The eccentric pivot stud in the carriage must be positioned at the exact center of the vector gear before the racks are mounted. Replace the vector gear on the plate and fasten the four guide rollers. Position the carriage in its rails so that the pivot lies directly above the center of the gear, and wedge the carriage in this position.

Mount a surface gage on the plate and use a dial indicator to measure the eccentricity of the stud when the vector gear is turned. Reposition the carriage and turn the stud until the indicator readings vary a minimum amount for one revolution of the vector gear. The allowable maximum is shown on the assembly drawing.

Remove the carriage and stake a small amount of metal into the stud. Tap lightly, and support the carriage directly under the staking tool. A heavy blow may warp the carriage and cause it to bind in its rails.

If the stud must be replaced, refer to the detailed explanation on page 78.





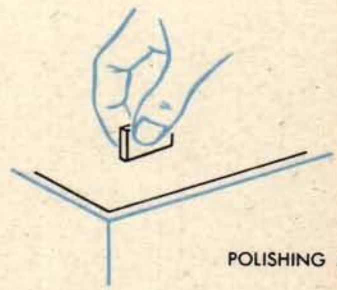
Fitting a new slide block

Use a fine oilstone to smooth burred or rough edges of the block. Remove any extremely sharp edges, but leave them square. It is very important not to round or chamfer the edges.

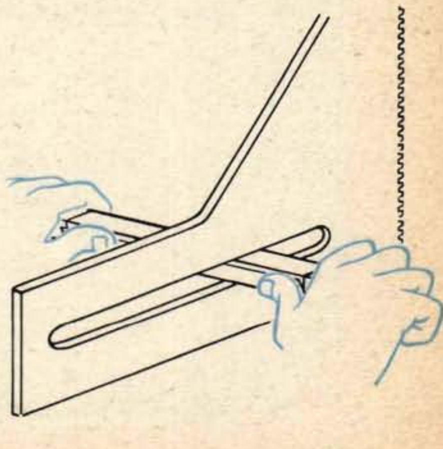
To reduce the width of the block, polish the sides on a piece of crocus cloth placed on a flat surface, using long, even strokes while holding the block square. Be sure to remove equal amounts from each side, so that the hole remains centered. Measure the block occasionally with a micrometer to be certain that the sides are parallel.

Polish the block until it fits closely in the widest portion of the slot. Polish the rest of the slot to fit the block, using crocus cloth wrapped once around a steel bar. Be sure to keep the slot sides square and flat.

Before trying the block in the slot, thoroughly wash, dry, and lubricate them both. The fit is correct when the block can be moved the full length of the slot. Move the block back and forth by hand until it travels smoothly from one end to the other. Finally, wash the block and slot again and lubricate.



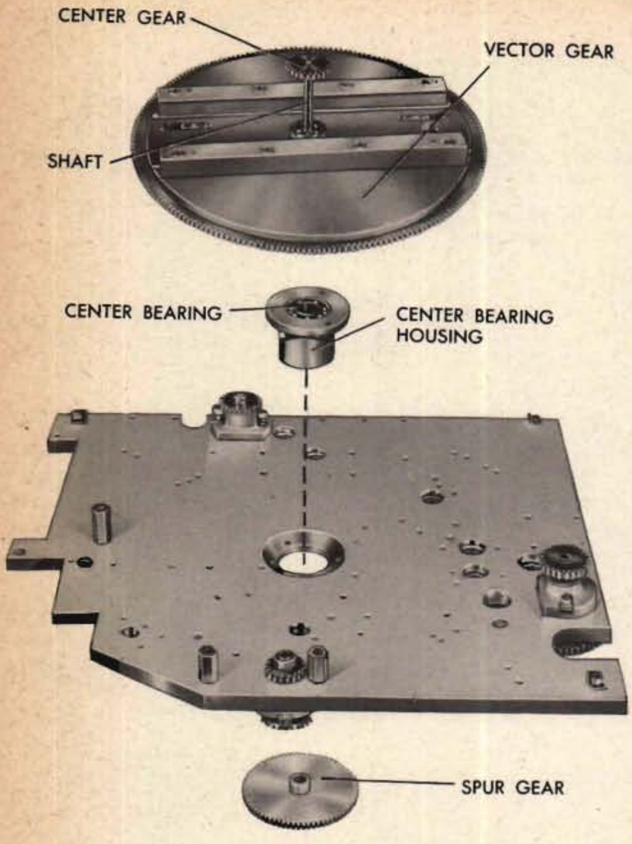
POLISHING A SLIDE BLOCK



POLISHING THE SLOT

Reassembling the unit

Wash and dry all the parts and lubricate each part as it is replaced.

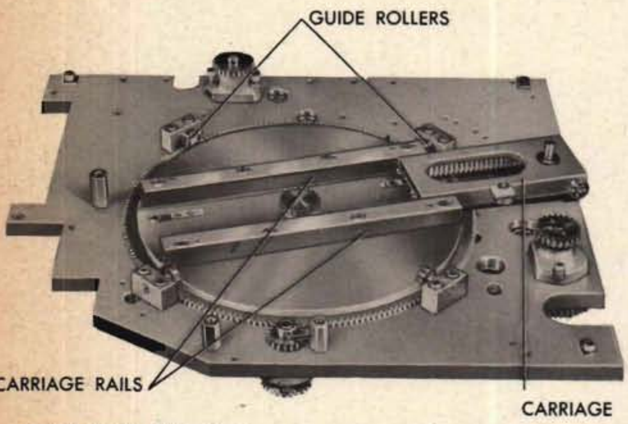


1 Replace the center bearing and housing.

2 Replace the vector gear.

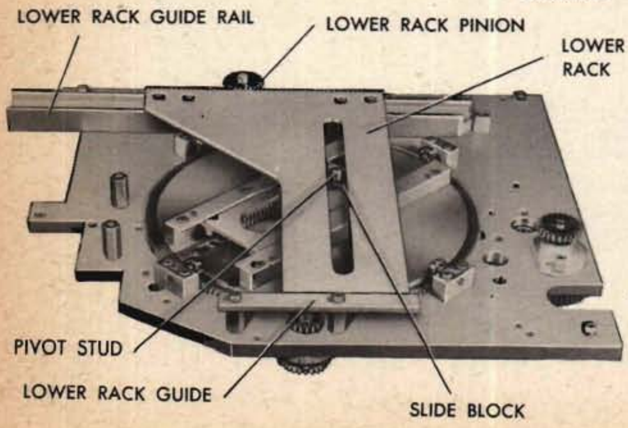
3 Replace the center gear and shaft.

4 Repin the spur gear to the bottom of the center shaft.



5 Replace the four guide rollers and secure them. Each guide roller is numbered so that it can be replaced where the corresponding number is stamped on the plate.

6 Slide the carriage on its rails.



7 Place the lower slide block on the pivot stud. Replace the spacers.

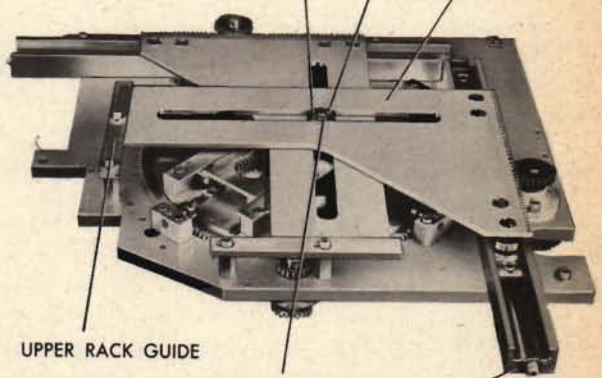
8 Mount the lower rack, guide rail and rack guide, and fasten them in place. Be careful to mesh the rack teeth with the pinion.

9 Tighten the pinion mounting.

10 Place the upper slide block on the pivot stud.

11 Mount the upper rack, guide rail, and rack guide.

12 Replace the spacer and cotter pin on the pivot stud.



Bench checking the unit

1 Check the assembly of the unit against the assembly drawing.

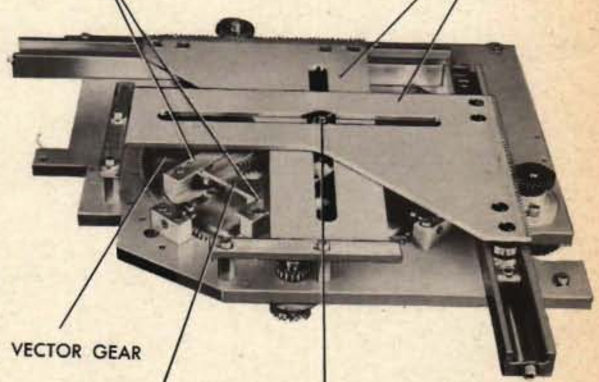
2 Position the carriage at one end of its travel. Check the racks for smoothness of operation and proper lost motion by turning the vector gear to move them through their full travel.

3 The eccentric studs in the racks and the pivot stud in the carriage should have been staked.

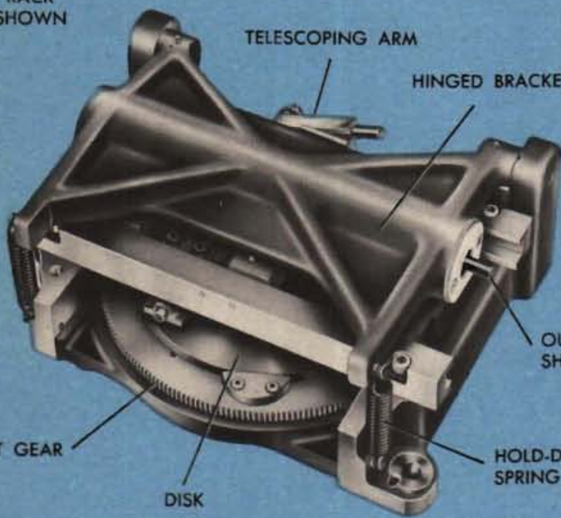
4 Lost motion between the carriage and its rails should be at a minimum. For the maximum allowable lost motion refer to the assembly drawing.

5 It should be possible to bring the carriage pivot stud to a zero point, where there is no motion of the racks when the vector gear is turned.

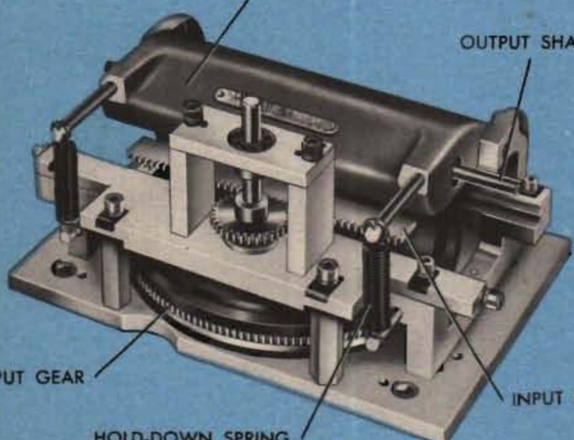
6 Check the smoothness of the frictions by screwing the clamp down two or three turns and rotating the gear. Final adjustment of the frictions is made after the unit is replaced in the instrument. Refer to the instrument OP for instructions.



DISK INTEGRATORS



FIVE-INCH DISK INTEGRATOR



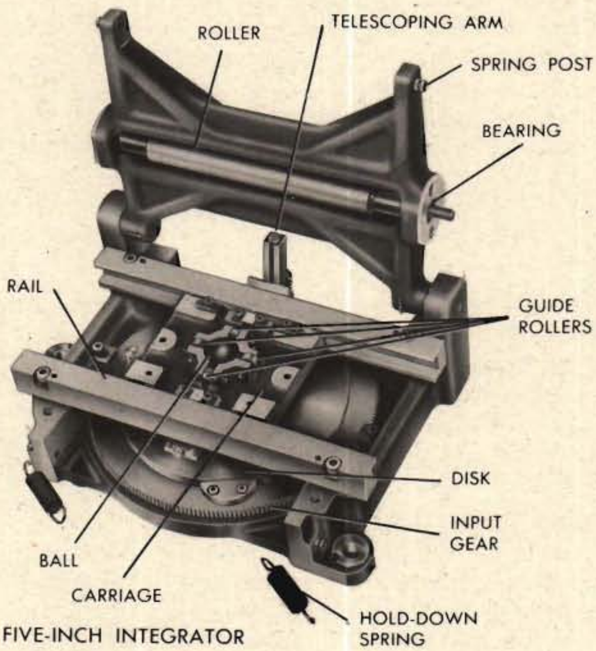
FOUR-INCH DISK INTEGRATOR

The four-inch disk integrator and the five-inch disk integrator are similar in construction and function. The inputs are carried by the disk spur gear and the carriage rack. The output is carried by the roller shaft.

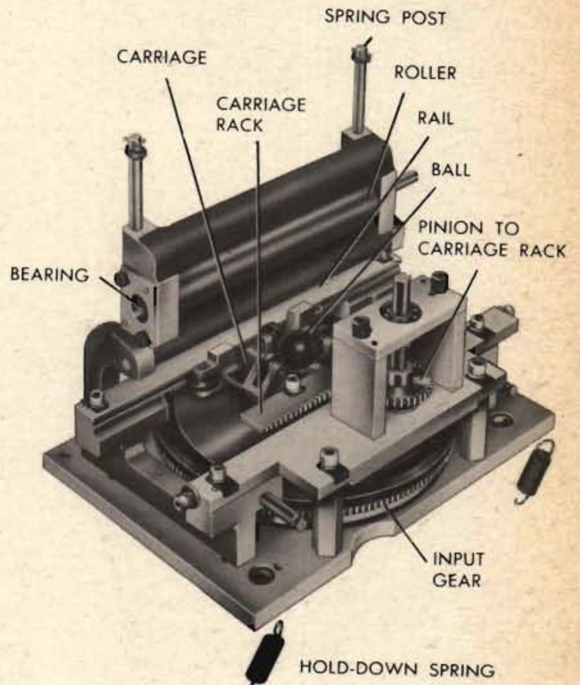
The four-inch unit is more simply constructed. It does not have the tilting rollers on the ball guides nor the telescoping carriage arm which are found on the five-inch integrator. Its springs are not as strong as those on the five-inch unit because it is used for purposes which require less power. Both units operate on the same principle, however, and their working parts are alike except for size. The procedure for locating trouble is basically the same for both units.

An integrator is sometimes mounted so that the hinged bracket holding the output roller may be swung away from the disk to permit repair in place. Integrator parts are easily removed and replaced, but the final adjustment of a reassembled unit demands great care and attention.

Integrator troubles are closely related because the moving parts are held against each other by powerful springs. Jamming of one part may be accompanied by slipping of another. A scratch or burr on one surface will be transferred to all the parts with which the damaged part makes contact. Therefore in trouble shooting, when one of the balls, the roller, or the disk is found damaged, always inspect the other three parts for damage. If the unit must be removed for repair, consult the instrument OP for instructions.



FIVE-INCH INTEGRATOR



FOUR-INCH INTEGRATOR

Typical symptoms

If a test analysis and unit check tests indicate that the source of trouble in an instrument is in an integrator, clean the parts as well as possible with a solvent and inspect the unit for one or more of the typical symptoms listed below.

JAMMING: The disk, the carriage, or the output roller cannot be moved by hand.

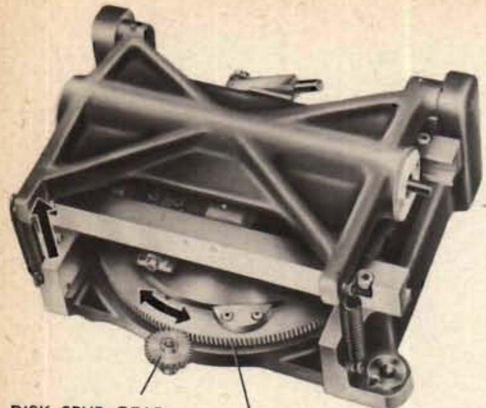
STICKING: The disk, the carriage, or the output roller moves sluggishly, or resists moving past certain points.

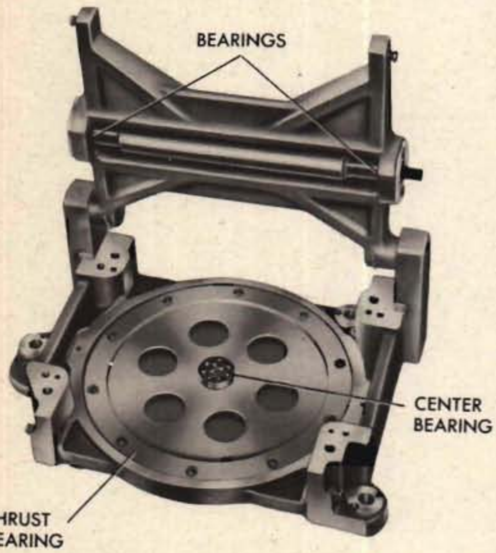
EXCESSIVE LOST MOTION: Too much side play exists between the carriage and its rails, or between the balls and their guide rollers.

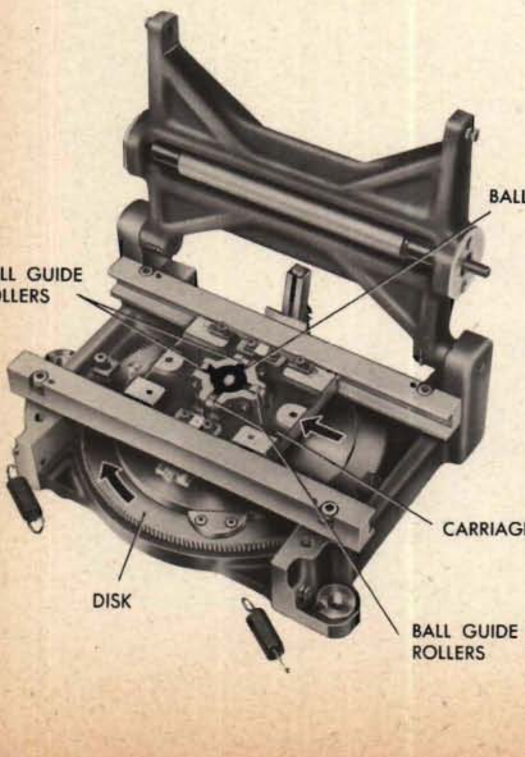
SLIPPING: Turning the disk and moving the carriage results in only intermittent movement of the roller shaft.

Locating the cause

Disk: jamming or sticking







If the disk is jammed, the trouble may be in its mesh with the disk spur gear, in the disk thrust bearings, or in the disk center bearing. To check the spur gear mesh, relieve the spring tension slightly with one hand while trying to turn the disk with the other. If the disk does not turn, inspect the mesh for damage or dirt where the disk gear and the spur gear are in contact. Repair can usually be made in place. If the cause of trouble is not found in the gear mesh, the unit must be disassembled to look for dirt or damage *in the disk thrust bearing* or in the disk center bearing.

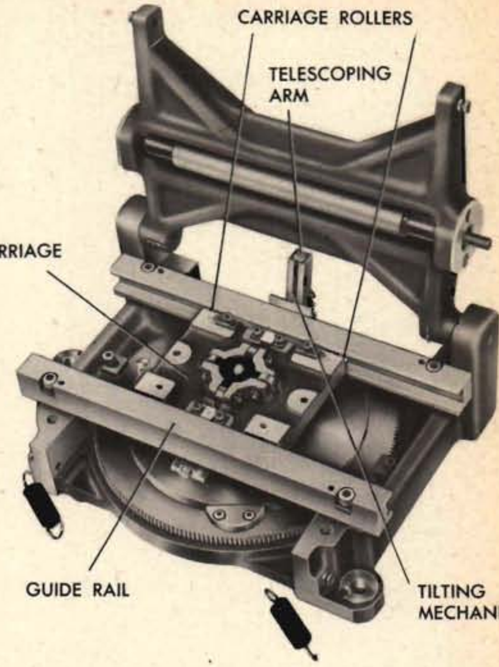
If the disk is sticking, the trouble may be caused by dirt on the disk surface, dirt or damage at the gear mesh with the spur gear, or a damaged thrust bearing or center bearing. A disk may also stick because the balls or roller are dirty or damaged.

Dirt on the disk surface is the most common cause of sticking. Clean the disk thoroughly with a lint-free cloth moistened in solvent. If there is dirt on the disk, it will also be found on the balls and roller. Clean them too. Spread a thin layer of grease over the disk surface before trying the disk for smooth operation.

To check for other causes of sticking, turn the disk by hand with the carriage at different positions along its travel. Check the number of times the disk sticks in the course of one revolution. If the disk sticks the same number of times during each revolution regardless of the carriage position, the trouble may be caused by dirty or damaged disk gear and pinion teeth, or a damaged thrust bearing or center bearing. Sometimes the gear mesh may be checked by inspection and repaired without removing the unit. If the disk sticks only at one position of the carriage, the trouble may be caused by a dirty or damaged disk surface. If the disk sticks several times during each revolution when the carriage is farthest away from the center, fewer times when near the center, and not at all when the carriage is centered, the trouble is caused by dirty or damaged balls, guide rollers, or output roller. Repairing of any of these parts usually requires disassembly of the unit.

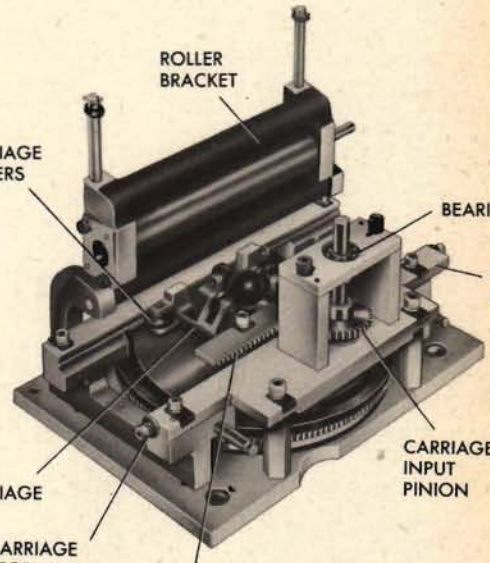
Carriage: jamming or sticking

If the carriage is jammed within its normal travel, the trouble may be caused by damaged rack teeth, carriage rollers, roller-tilting mechanism, or guide rails, by a frozen bearing on the carriage input pinion shaft, or by dirt in any of these parts.

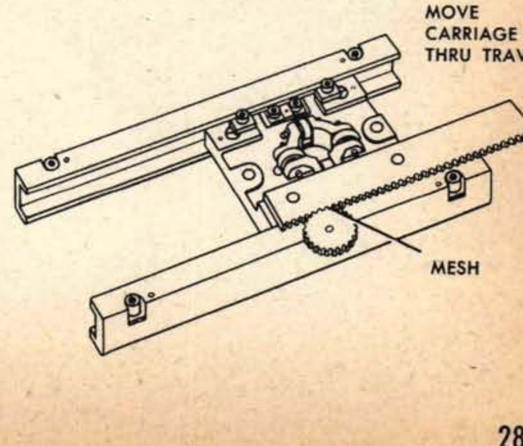


The unit must be disassembled to repair any of these parts. A bench inspection is usually necessary to determine the specific cause of the jamming.

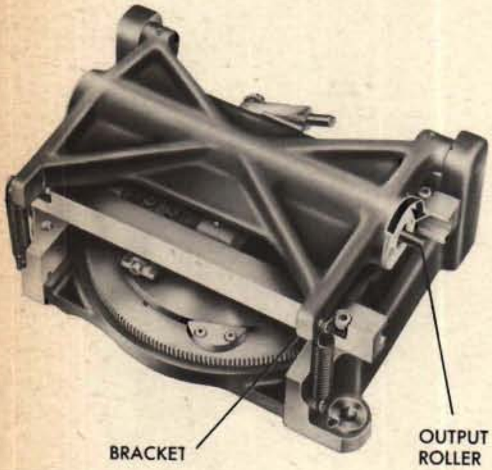
If the carriage is sticking, the trouble may be caused by dirty or damaged carriage rack teeth, carriage rollers or guide rails, or by irregularities in the roller or the disk. All of these troubles require disassembly for repair and are best checked when the unit is on the bench.



To make sure that the trouble is not caused by sticking balls when they move across a groove worn in the disk or the roller, lift the roller bracket sufficiently to relieve the spring pressure and check the carriage response by moving it the full range of its travel. Sticking caused by contact with irregularities in either the disk or the roller will not be felt when the spring pressure is removed. If the trouble is in the roller or the disk, the unit must be disassembled for repair.



To check the mesh of the carriage rack and pinion, turn the input gear to move the carriage through the full range of its travel. Position the carriage at the tight spot and check the carriage input mesh. A tight mesh between the carriage rack and pinion will prevent the carriage from moving freely in its rails. The unit usually must be disassembled and the rack readjusted.



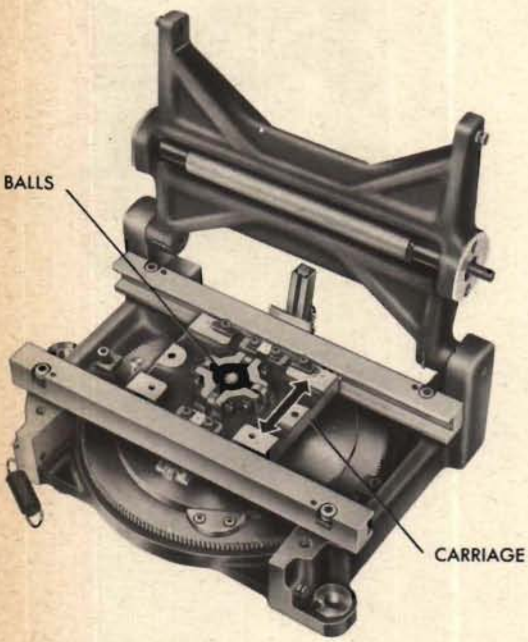
Output roller: jamming or sticking

To check for jamming of the output roller, lift the bracket against the spring tension with one hand and try to turn the output roller with the other. If the output roller cannot be turned by hand, the trouble is a dirty or damaged bearing on the roller shaft. An integrator which has been operated with a jammed output roller may also have flattened balls or a scored disk, or output roller. The unit must be disassembled to replace the damaged parts.

If the roller can be turned, but moves sluggishly or resists moving past certain points, the bearings are dirty or damaged. Check to be sure no damage has been done to the roller, balls, or disk. The unit must be disassembled to clean or replace the bearings.

Balls: jamming or sticking

The balls may jam or stick if foreign matter enters between the ball and the guide rollers. The bracket can be lifted to inspect, clean, or replace the balls.



Excessive lost motion

One source of lost motion is the play between the carriage rollers and their rails or between the balls and their support rollers. To check for this lost motion, shake the carriage back and forth between the rails. If there is lost motion anywhere along the rails in excess of 0.001 inch, the unit must be disassembled for repair. Excessive lost motion between the balls and their support rollers requires disassembly and replacement of the carriage or rollers.

On the five-inch integrator, a shifted or loosened eccentric center stud will cause the integrator output to be in error, as indicated by a B test. To check for a loose center stud, inspect the bottom of the unit to see whether the stud slot has shifted from the position where it was staked.

A loose eccentric stud may cause the mesh between the disk gear and the input gear to have excessive lost motion or to jam. To adjust and stake the center stud, the unit does not need to be disassembled. The center stud of the four-inch integrator is fixed.

To inspect for worn disk, balls, and roller, the unit must be disassembled.

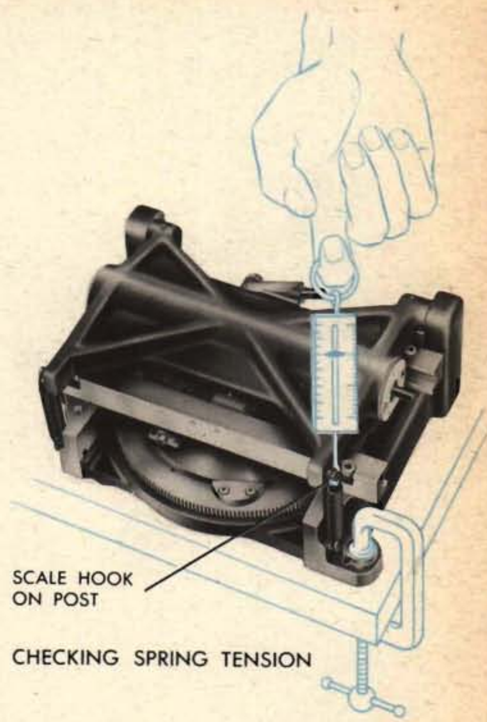
Slipping

The principal cause of slipping is weakness of the two hold-down springs, which may have rusted or become fatigued. To check for weak springs, move the carriage to the end of its travel away from the center. Turn the disk and try to hold the output roller. If the output roller can be easily stopped, the springs should be replaced. On the five-inch integrator, each spring should exert a pull of 9.2 pounds $\pm 10\%$ when in position. If the unit is on the bench, this pull can be checked by hooking a spring scale to one spring post. A pull of 17 pounds on the scale should not lift the roller bracket.

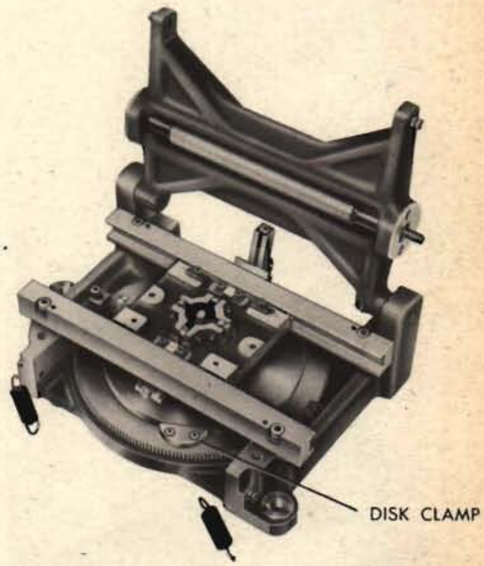
On the four-inch integrator, each spring should exert a pull of 2.75 pounds $\pm 10\%$. If a pull of 5 pounds lifts the roller off the balls, replace the springs.

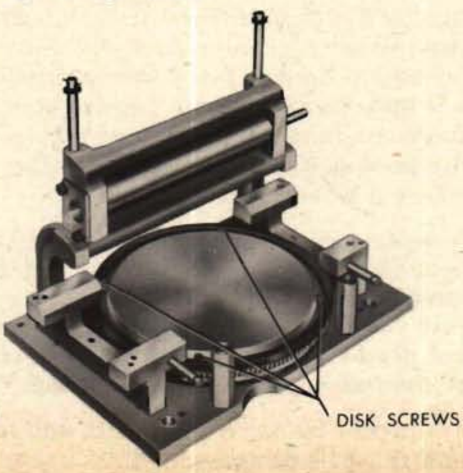
If there is any doubt as to whether or not the springs are weak, replace them both.

Slipping may also be caused by a loose disk. To check for a loose disk on a four-inch integrator, inspect the four special flat-head screws, to make certain that they are tight. The rolling parts may hop and slip if there is a groove or scratch on the disk, balls, or roller, or a flattened area on the balls or roller. The unit must be disassembled to inspect these parts. On the five-inch integrator it is not likely that the disk will slip on the disk gear. To check the disk, turn the disk input until the clamp that holds the disk to the gear can be reached. Tighten the two screws in the clamp. Make sure that when the clamp is tight the disk is tight. On the four-inch integrator, the four screws holding the disk in place may be tightened.

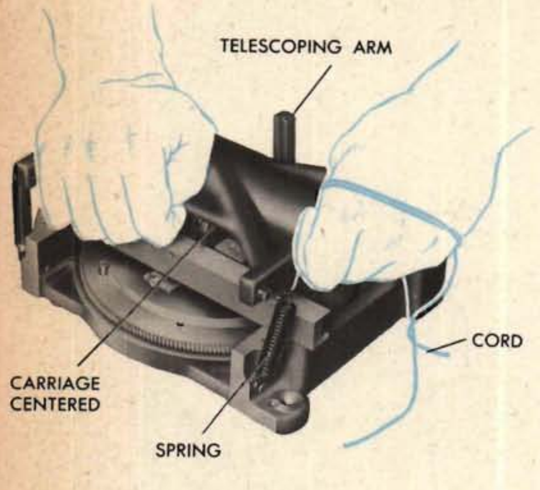


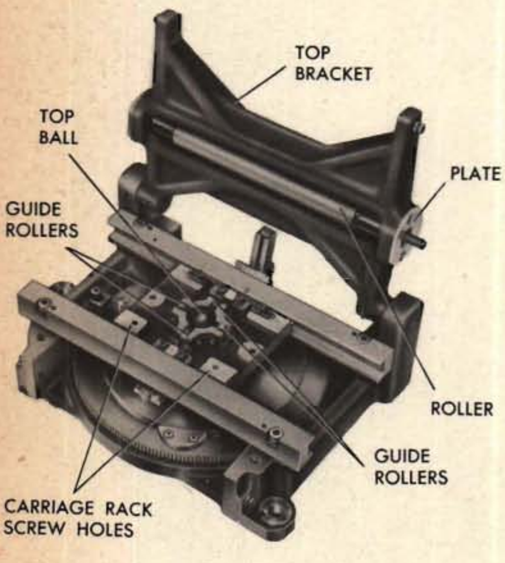
CHECKING SPRING TENSION

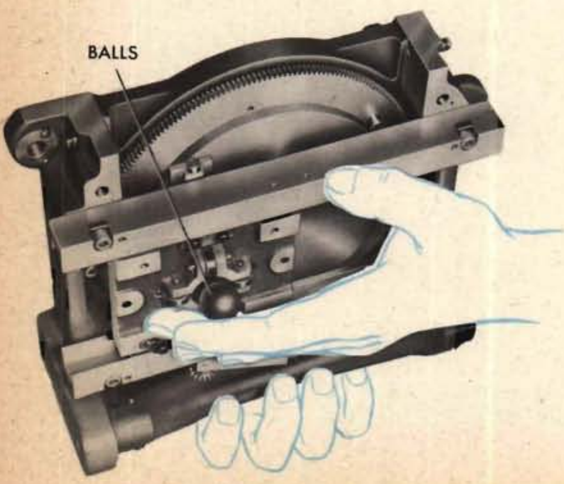




Disassembling the five-inch unit







1 Place the unit flat on the bench. Insert a loop of strong cord under the top loop of one hold-down spring and lift the spring loop off the spring post. Remove the second spring in the same manner.

2 Move the carriage to the center of its travel so that the telescoping arm will not be damaged when the top bracket is swung back.

3 Swing the hinged top bracket back.

4 Use a lint-free cloth moistened with solvent to wipe the roller clean. Inspect the surface. Slowly and lightly turn the roller to check its freedom of rotation.

5 Remove the roller only if replacement or cleaning of bearings is necessary.

6 Remove the plate from the shaft extension end and tap the opposite end of the roller shaft with a light plastic hammer until it starts to move. The roller may be pushed out through the bearing hole.

7 Before removing the two balls, check for excessive lost motion between the top ball and its guide rollers. A 0.001-inch feeler gage should fit between the ball and any roller. Do not force the gage. If a 0.002-inch gage can be slipped between the two parts, the clearance is too great and should be reduced.

8 Remove the carriage rack and pinion gear.

9 Remove the balls by tilting the unit. Hold one hand over the carriage to catch the balls as they roll out.

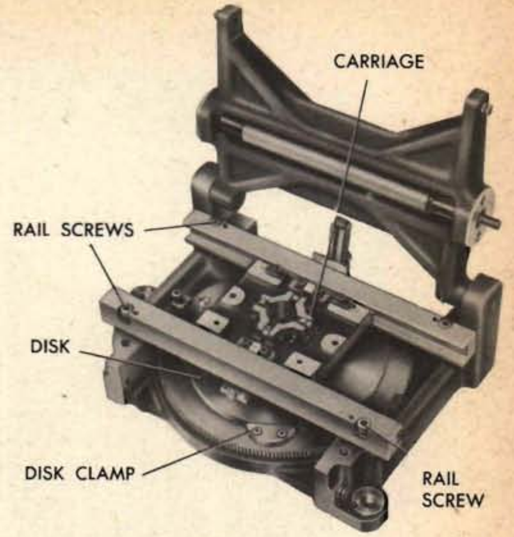
10 Remove the screws holding both carriage rails and tap the underside of both rails lightly to raise them evenly off their dowels. Mark the front and back rails to identify them.

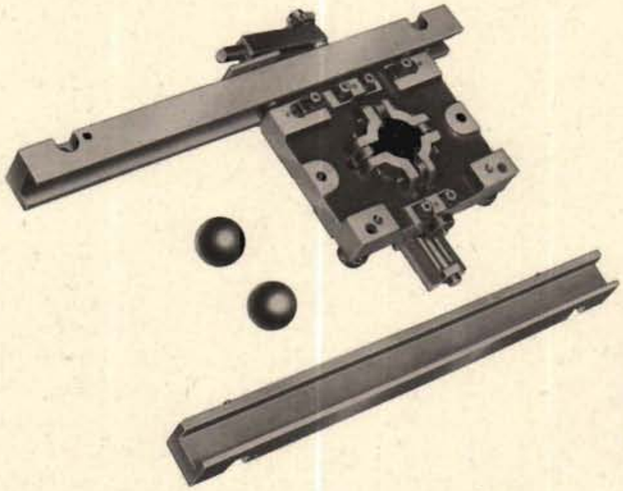
11 Slowly lift the rails and the carriage together.

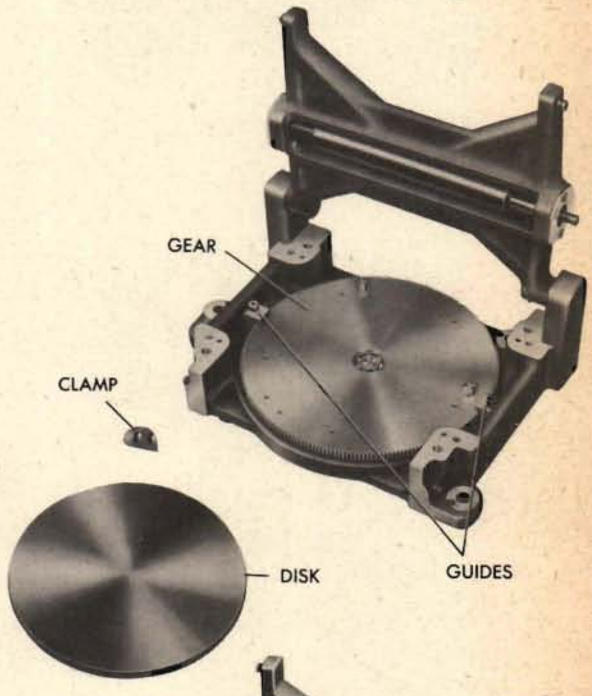
12 Wipe the disk clean with a lint-free cloth moistened with solvent. Inspect the disk surface for irregularities. Do not remove the disk from the gear unless either one is defective, or parts below the gear require inspection or repair.

13 To remove the disk, remove the clamp that presses against the outside of the disk. The disk can then be lifted off.

14 To remove the disk gear assembly, remove the two guides and raise the gear off the center stud.

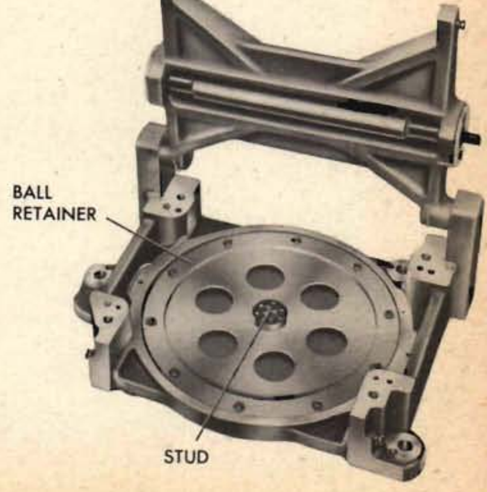


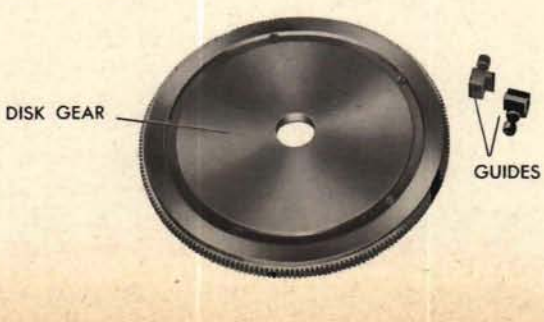




15 Lift off the ball retainer.

16 The center stud should not be removed unless a new one is to be installed. If it is loose, it can be adjusted and tightened in place.



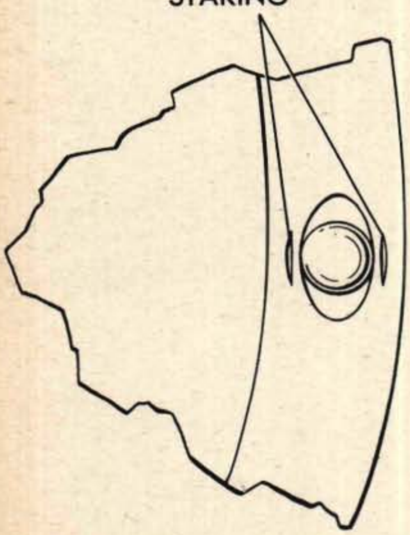


Repairing the parts: five-inch unit

Replacing the eccentric center stud

Drill into the old stud to remove the flange. Drive out the old stud with a punch and hammer and clean the hole. Grease a new stud and insert it in the hole. Support the frame upside down, resting the assembly on a support on the stud shoulder. With a hammer lightly tap all around the raised lip to peen the lip into the countersink in the frame. Turn the stud at intervals during this process so that the stud is not tightened too much. The stud is adjusted to its final position and staked during final assembly. For a detailed explanation of removing and replacing parts which are riveted in this way, see pages 77-79.

THE BALL RETAINER



Repairing the ball retainer

Each ball in the retainer is held in its slot by staking, which keeps the ball from falling out, but allows it to move in all directions. Each ball should rotate freely. Wash and dry the retainer and look for worn or broken balls. Be particularly careful in this inspection if the ball races are damaged. Remove any chipped or scratched ball by supporting the frame around the ball and driving the ball out with a punch and a light hammer. Insert a new ball, and again supporting the frame around the ball, stake lightly in the old stake marks to retain the ball. Turn the ball to see that it is free. Place the retainer in position on the center stud. Make sure that the retainer is sufficiently flat to allow all the balls to rest on the raceway. If the retainer is bent, remove it and straighten it by hand pressure, checking straightness by eye.

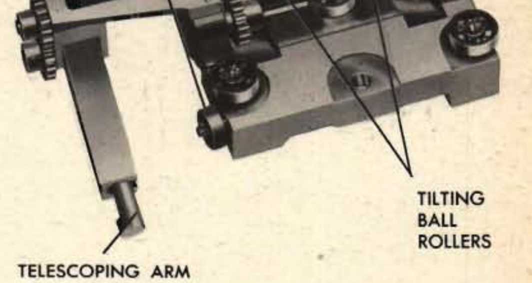
Repairing the disk

Both sides of the disk may be used. Wash the disk with an approved solvent and inspect the side which has been in use. Small rust spots or hair scratches may be smoothed down by polishing them with crocus cloth wet with oil. Back the cloth with a flat steel block. Carefully inspect the center of the disk. If any depression is found there, the disk must be reversed or replaced. Turn the disk over and inspect the other side. If both sides have depressions, grooves, rough spots, or scratches, the disk must be replaced. Handle the disk only on the edges, never on the faces, because perspiration on the fingers may start corrosion. Wipe the surface with a clean lint-free cloth to prevent scratching the polished surface. Coat the underside with a film of grease.

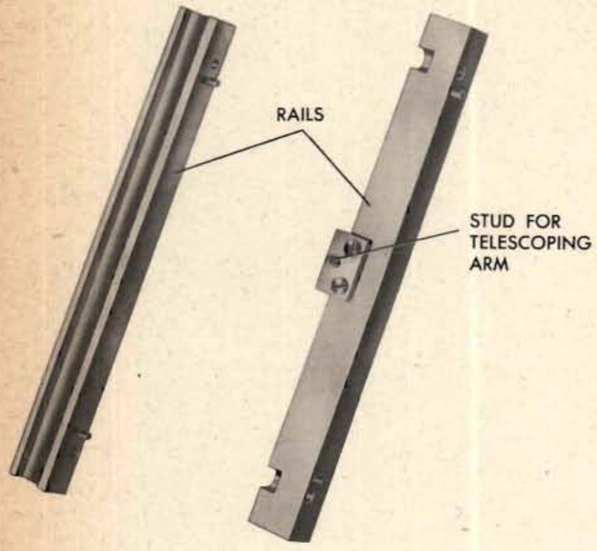
PROPER METHOD OF HANDLING DISK

Repairing and installing new carriage rollers

Wash the carriage thoroughly with an approved solvent to remove all dirt and old lubricant from the bearing rollers. Check all rollers for smoothness. Replace rusted, rough, or sticky bearings which cannot be washed clean. The seven rollers which position the carriage on the rails may be lifted off their studs after the cotter pins have been withdrawn from the stud ends. The two fixed lower ball guide rollers may also be removed after the cotter pins have been withdrawn. The two tilting ball guide rollers and the four upper ball rollers may be taken out by removing the cotter pins and withdrawing the roller shaft. Do not lose the two spacers that fit on either side of each of these rollers. A ball guide roller having grooves on its face should be replaced.

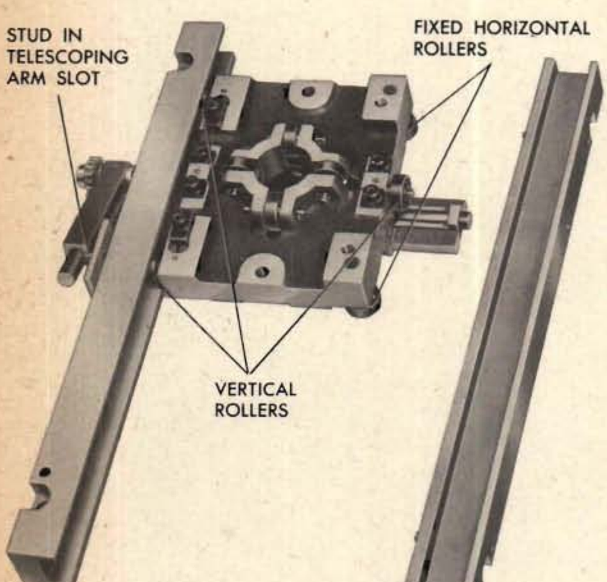


UNDERSIDE OF CARRIAGE



Repairing the carriage rails

Wash the carriage rails with solvent and polish them with tissue. Inspect the roller paths for dirt or damage. Check carefully for imbedded material. Put the carriage into its rails, and mount this subassembly on the casting. Test the carriage travel in the rails. The horizontal rollers should have an up-and-down play of approximately 0.001 inch. Polish rough or high spots on the rails by stroking the roller path with a square steel bar wrapped in crocus cloth. Wash the rails thoroughly after completing this work.



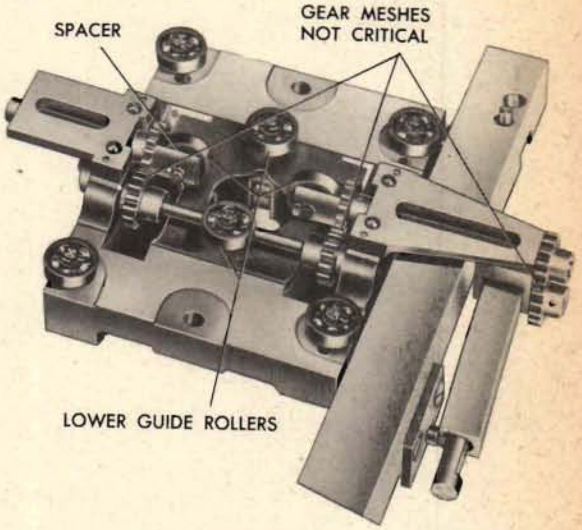
Repairing and replacing the carriage studs

Check for bent roller studs. To straighten bent studs, first remove the roller. Then, with the stud resting on a flat metal surface, gently tap the stud end until the stud is straight. The three vertical rollers have studs pressed into blind holes in the carriage. They are held by straight pins. To remove a stud, drive out the straight pin and pull out the stud. Fit the roller to the new stud by polishing the stud. Lubricate the stud and insert it in the hole, tapping it in with a plastic hammer. Carefully drill through the old pin hole with a drill the same size as the pin. Tap in the straight pin and stake both ends of the pin to retain it in position.

The fixed horizontal rollers, two guiding the carriage and two guiding the lower ball, are on riveted studs. To remove a riveted stud, drill out the countersunk head and drive out the shank. In riveting a new stud, the assembly must be supported at the stud shoulder. The carriage guide roller studs must have their riveted heads filed flush with the rack mounting surface.

Adjusting and replacing the roller-tilting mechanism

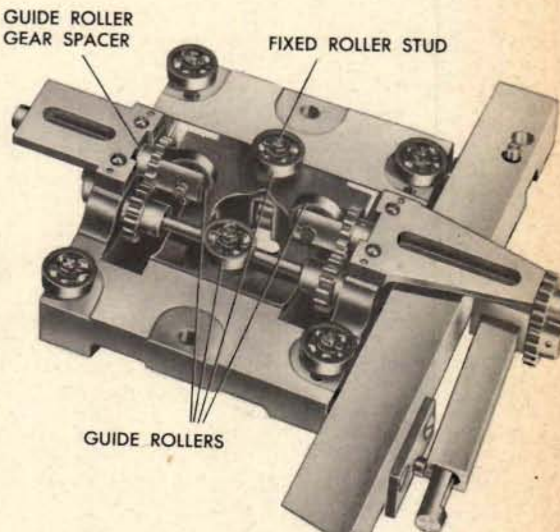
Move the carriage through its full travel to check the smoothness of the roller-tilting mechanism. Repair or replace damaged gears or bent shafts. All parts on the shaft assemblies are held with straight pins. If the gear meshes are too tight, reposition the gears. Excessive lost motion in the gear meshes of the roller-tilting assembly is not critical. A roller may be replaced by removing one cotter pin and withdrawing the roller shaft. Do not lose the two spacers which position the roller in its fork.



ROLLER-TILTING MECHANISM
(UNDERSIDE)

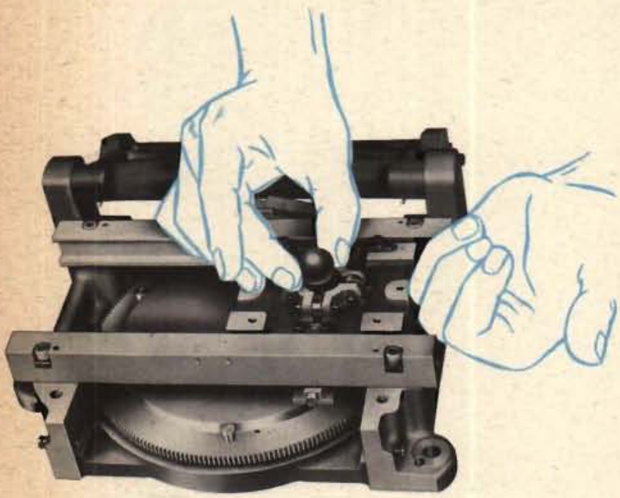
Reducing excessive lost motion between the lower ball and its guide rollers

Excessive lost motion between the lower ball and its guide rollers can sometimes be eliminated by replacing the rollers. On a new unit this lost motion does not exceed 0.0008 inch, but through use and lack of lubrication, these rollers may develop play.



If replacing rollers does not reduce excessive lost motion sufficiently, it can be eliminated, in the case of the tilting rollers, by changing spacers. THIS METHOD IS NOT RECOMMENDED AS STANDARD PRACTICE AND SHOULD NOT BE USED UNLESS AN EMERGENCY JUSTIFIES IT, AND THEN ONLY AS A TEMPORARY REPAIR UNTIL A REPLACEMENT CARRIAGE ASSEMBLY IS AVAILABLE.

A tilting roller may be moved toward the ball by using a thicker spacer behind the guide-roller gears, but the spacer on the other end of the shaft must be reduced correspondingly. Always move both rollers in equal distances.

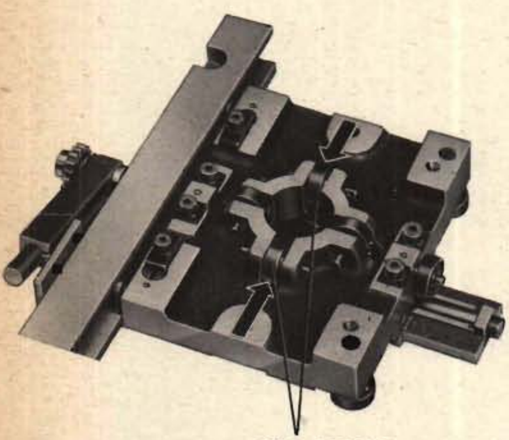


REPLACING BALLS
IN THE CARRIAGE

To move a fixed roller stud slightly towards the ball, tap it gently after the roller is removed.

To check the clearance of these rollers, mount the carriage on the rails. Slip one finger between the carriage and disk so that it reaches the hole. Drop the lower ball on the finger, and slowly remove the finger until the lower ball touches the disk. Failure to follow this procedure may result in denting the disk.

When the ball is in place, insert a feeler gage between the ball and guide roller. Clearance should be not more than 0.001 inch.

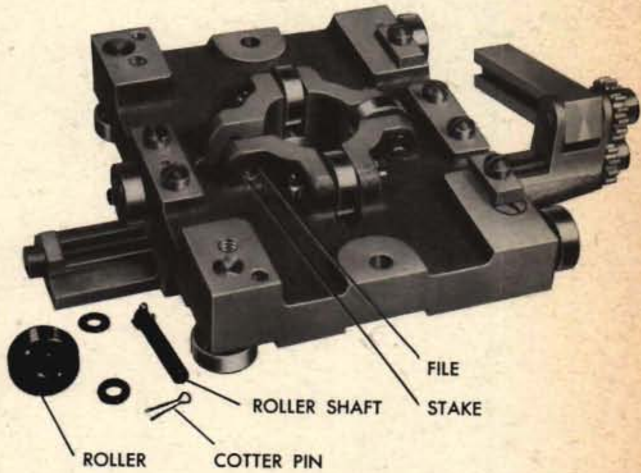


Reducing excessive lost motion between the upper ball and its guide rollers

Excessive lost motion between the upper ball and its guide rollers can sometimes be eliminated by replacing the rollers. On a new unit this lost motion does not exceed 0.0008 inch. Through use and lack of lubrication these rollers may have developed play. If replacing the guide rollers does not sufficiently reduce lost motion, moving the roller shafts closer to the ball will reduce it further. The shafts on opposite sides of the ball must be moved equal distances to maintain the vertical alignment of the balls.

To reposition a roller shaft, take the carriage from the rails and remove the roller and the shaft. Using a round needle file, enlarge the hole slightly by filing towards the center of the carriage. A few strokes of the file should be sufficient; do not file too much. Replace the roller and shaft. Mount the carriage on the rails.

Slip one finger between the carriage and disk so that it reaches the hole. Drop the lower ball on the finger, and set the upper ball on top of the lower one. Slowly remove the finger until the lower ball touches the disk. Failure to follow this procedure may result in denting the disk.



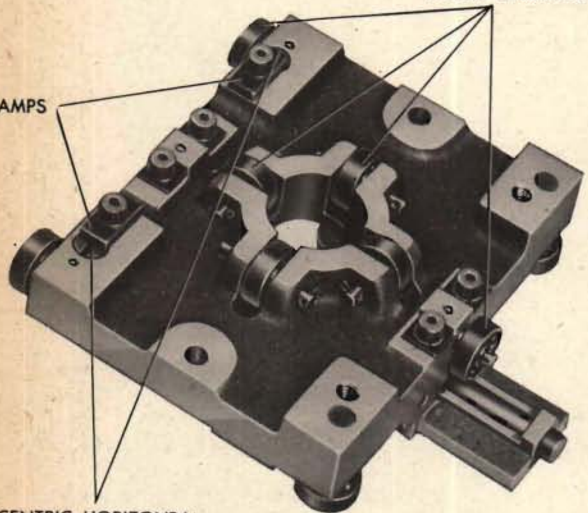
When the balls are in place, press the roller shaft toward the upper ball and insert a feeler gage between the ball and guide roller. Clearance should be not more than 0.001 inch. Repeat the filing and checking procedure until lost motion is sufficiently reduced.

Remove the balls from the carriage and the carriage from the rails.

With the shaft in place, stake the carriage metal on the side of the shaft farthest from the ball, using a small round punch and a light hammer. This flows the metal of the carriage into the enlarged hole and holds the shaft in place. Tap gently and uniformly to avoid breaking the metal.

NOTE:
If the shafts are bent, the holes too much enlarged, or the lost motion of the ball over 0.002 inch, the carriage must be replaced.

Adjusting the carriage on its rails



Place a drop of oil in each of the carriage roller bearings and position the vertical rollers of the carriage on both rails. Be sure that the pin attached to the rear rail is in the slot of the telescoping arm. With the carriage in position between the rails, set the rails on the integrator frame with the dowels directly above the dowel holes. To lower the rails evenly into position, tap them lightly above the four dowels. Insert and tighten the rail screws.

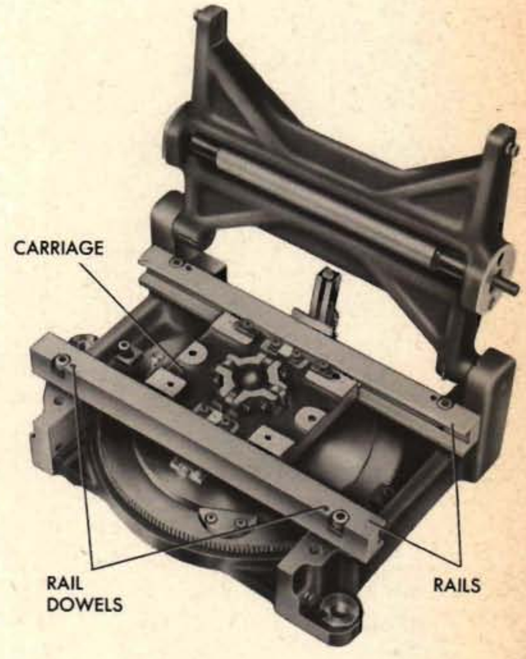
Move the carriage through its full travel, checking its side play all along the rails. This side play should be less than 0.001 inch; it can be controlled by turning the two eccentric horizontal studs. If there should be excessive side play of the carriage at one end of its travel and none at the other, one of the rails must be repositioned and redoweled.

Mount the input gearing assembly on the integrator frame. Hold the carriage against the rail, away from the eccentric studs, and move it through its travel to check the carriage-rack gear mesh for binding. If this carriage position causes excessive binding, it is necessary to move and redowel the rail nearest the mesh. If the mesh is satisfactory, the eccentric studs can be adjusted by loosening the flat clamps above them and turning the studs.

Repositioning the rails

The rails must be parallel to each other and to the output roller axis. Also, when the carriage moves through its full travel, the centers of the balls should pass directly under the output roller axis.

Remove both rails and the carriage. Carefully drive the dowels out of the rail to be moved and then replace the rails and carriage in the unit. Replace the rail screws. Shift the rail without dowels until the balls, rails, and roller are in the relative positions described above. If the up-and-down motion of a spring post is at a minimum when the carriage is run through its full travel, the rails are parallel to the roller axis. (Measure spring-post motion with a dial indicator.) While positioning the rails, if too much side play develops between the carriage and the rails, reduce it by adjusting the eccentric carriage roller studs. If the mesh between the carriage rack and pinion is disturbed, reposition the rack. Tighten the rail screws and redrill the old dowel holes for oversize dowels. While drilling, protect the disk and carriage rollers with tissue.

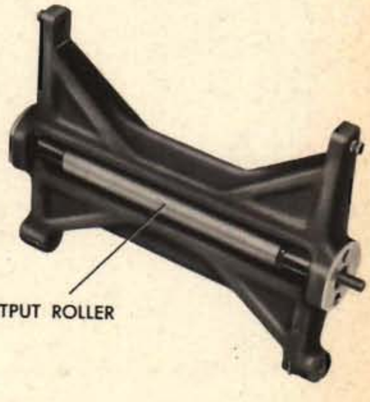


Positioning the carriage rack

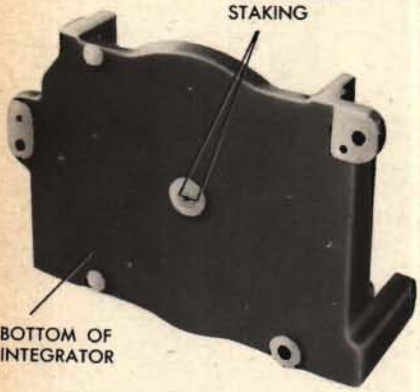
Remove the carriage rack and drive out the dowels. Mount the rack loosely in place. Mount the carriage input gearing assembly on the frame. Position the rack to obtain a smooth mesh with minimum lost motion throughout the carriage travel. Set the screws tight and remove the carriage. Protect the rollers while drilling and reaming for oversize dowels. Dowel the rack to the carriage. Replace the carriage in its rails and recheck the mesh.

Repairing and replacing the output roller

Because the outside diameter of the roller is finished to an exact dimension to obtain the required unit output, the output roller cannot be ground or refinished to remove grooves, flats, or scratches. It should be replaced. Small rough spots, hair scratches, and rust may be smoothed by polishing the surface.



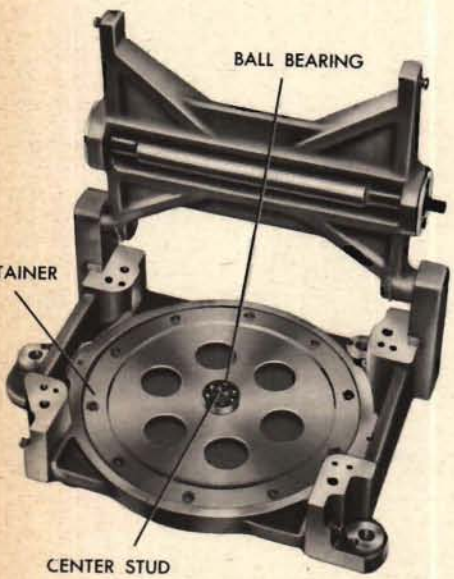
Reassembling the five-inch unit



Before reassembling the unit, wash the parts with an approved solvent and dry them. Put a drop of oil in each ball bearing. Apply a thin film of grease to the roller, disk, balls, and rails.

1 Inspect the staking of the center stud to determine whether the stud has been turned from its original position. With a screw driver check the tightness of a new center stud, or one which has been turned from its original position. To tighten a loose stud, turn the frame upside down and support the assembly on the stud shoulder. Using a light hammer, tap uniformly around the stud flange until considerable force is required to turn the stud. Do not stake a new stud or one which has been turned, until the final adjustment has been made, after complete assembly.

2 Wash the upper and lower ball races in solvent and dry them with a clean, lint-free cloth. Look for rust or scratches in the path traveled by the balls. Hair scratches or rust spots may be smoothed by polishing. Cover the races with a thin film of grease before replacing the ball retainer.



3 Place the ball retainer on the center stud.

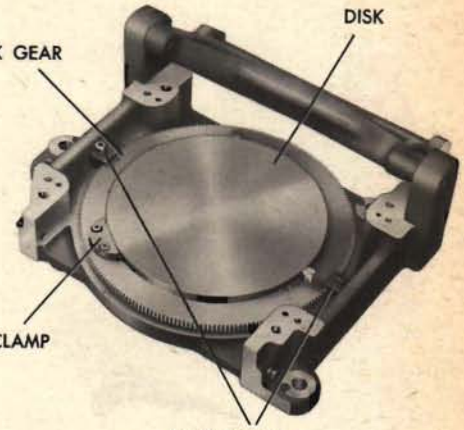
4 Place the ball bearing on the center stud above the retainer.

5 Place the disk spur gear on the center stud bearing.

6 Handle the disk only on the edges, never on the faces, because perspiration in the pores of fingers is sufficient to start corrosion of the disk. Wipe the surface with a lint-free cloth to prevent scratching the polished surface. Coat the underside with a film of grease. Place the disk on the disk gear.

7 Turn the disk until the flat is opposite the two clamp screw-holes in the gear, and replace the disk clamp. Make sure that the disk is tightly in place when the clamp is tight.

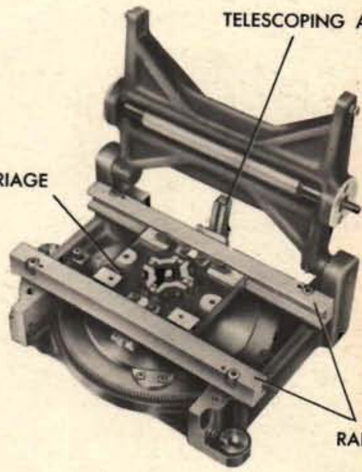
8 Reinstall the two disk guides. Coat the disk with a thin film of grease. Turn the disk gear slowly to check for freedom and smoothness of rotation. Spin the disk. It should spin to a gradual stop.



9 Position the rails on the carriage rollers and secure the telescoping arm.

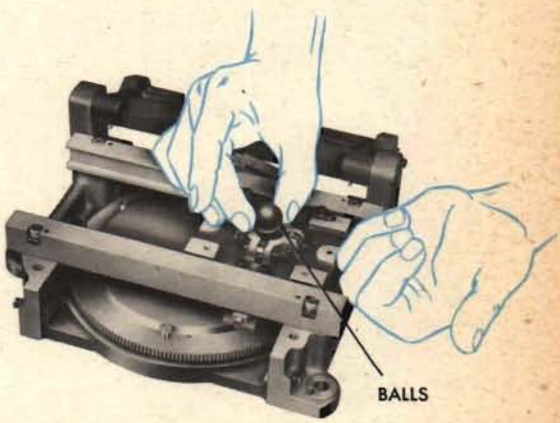
10 Mount the carriage and rails on the casting, lowering the rails evenly by tapping the dowels into the holes.

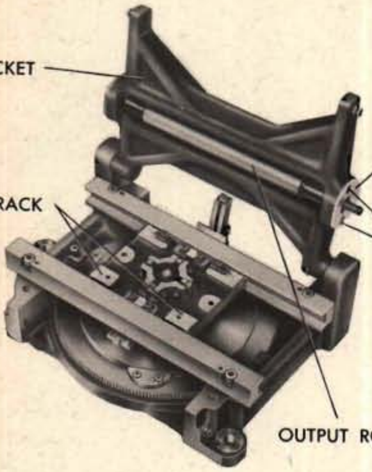
11 Run the carriage through its full travel. Check to be sure that the side play is less than 0.001 inch.



12 Slip one finger between the carriage and disk so that it reaches the hole. Drop the lower ball on the finger, and set the upper ball on top of the lower one. Slowly remove the finger so that the lower ball makes contact with the disk.

13 Insert a feeler gage between the upper ball and each guide roller and check to see that clearance is not more than 0.001 inch.





14 Mount the rack on the carriage. Mount the pinion gear.

15 Wash and inspect the output roller bearings and mount the roller and bearings in the hinged bracket.

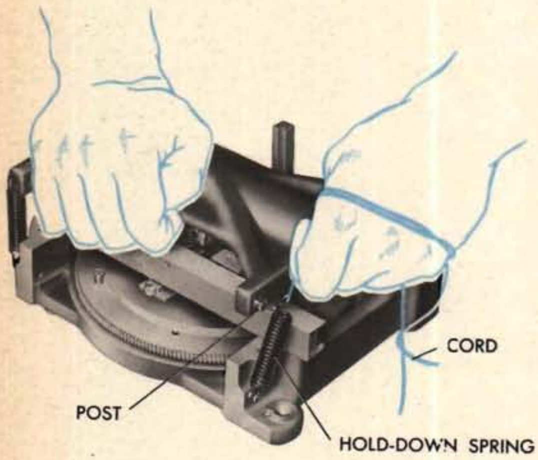
16 Mount the plate.

17 Stake the flat-head screws to keep them from working loose.

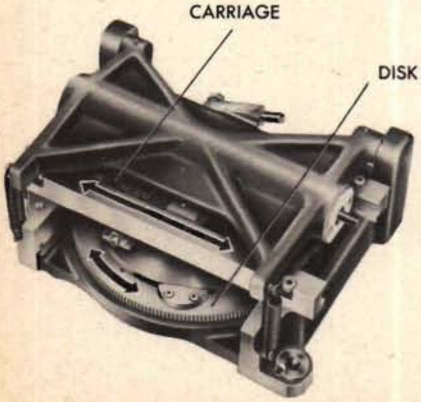
18 Spin the roller to check for smoothness of operation.

19 Spread a thin layer of grease on the roller.

20 Lower the hinged bracket into position.



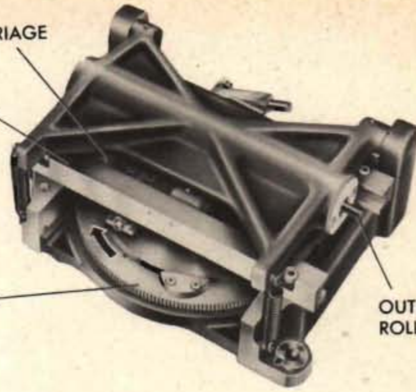
21 Hook one hold-down spring over the lower spring post. Pass a loop of strong cord through the upper spring loop and raise the spring until it can be hooked over the upper spring post. Install the second spring in the same way.

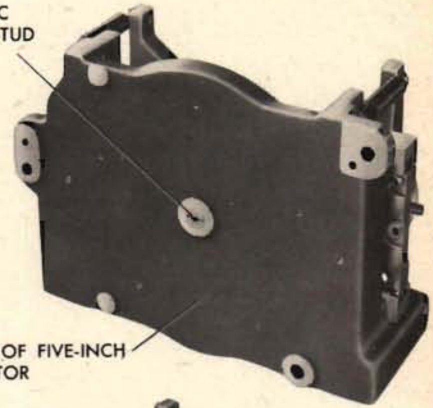


22 Move the carriage through its travel and turn the disk to check the unit for smooth operation.

Adjusting for zero output

Turn the disk and adjust the carriage position until the output roller movement is at a minimum. Wedge the carriage in this position by placing a wedge between the rack and the rail. Turn the disk to recheck the carriage position after wedging. Turn the disk in the opposite direction. If the balls are at dead center on the disk, the roller will not turn. If the roller movement cannot be stopped by repositioning the carriage, the eccentric center stud on the bottom of the unit should be turned a few degrees. Try again to reposition the carriage to obtain a zero output which remains stable when the disk is turned first in one direction and then in the other. Repeat the operation of turning the stud slightly and repositioning the carriage until a stable zero output is obtained. Then stake a small amount of metal into the slot in the stud to prevent the stud from turning. Remove the wedge.





Bench checking the unit

Before reinstalling, check the assembly of the unit against the assembly drawing. See also that the following requirements are met:

1 A force of 1/2 ounce will move the carriage through its entire travel when the roller bracket is lifted.

2 Side motion of the carriage between its rails does not exceed 0.001 inch.

3 The disk clamp prevents the disk from slipping on the disk spur gear.

4 Balls, roller, and plate are free of pits, grooves, rust, or scratches.

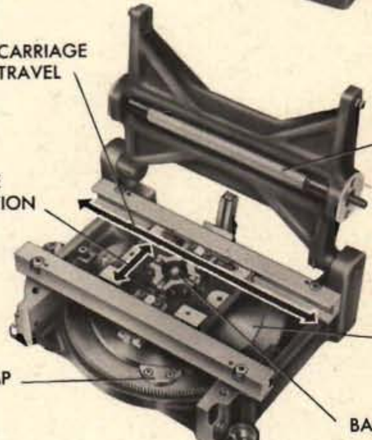
5 A thin coating of grease has been applied to the disk and roller. The bearings have been oiled.

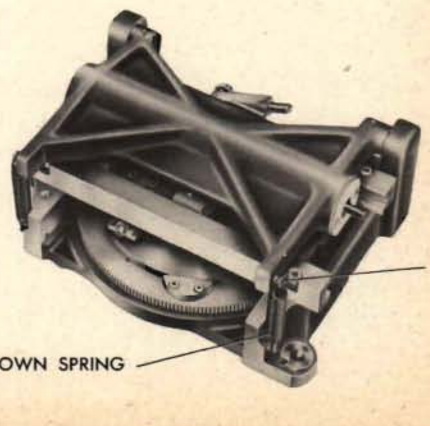
6 The hold-down spring tension is 18.4 pounds $\pm 10\%$.

7 The roller does not bind in its bearings when the unit is placed in different positions.

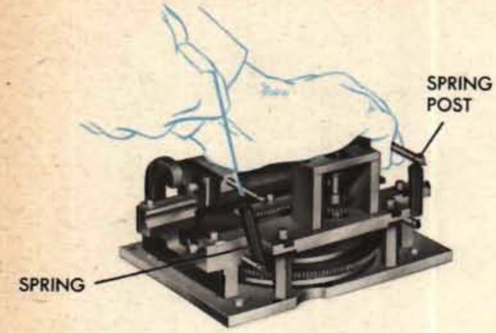
8 When the carriage is centered, a zero output is obtained for both directions of disk rotation.

9 Use an indicator to make sure that the up-and-down movement of a spring post does not exceed 0.020 inch when the carriage is moved through its normal path of travel.



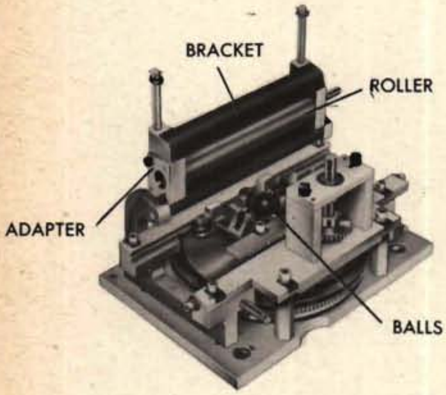


Disassembling the four-inch unit



1 Unhook the hold-down springs from the upper spring posts.

2 Raise the roller carriage bracket.

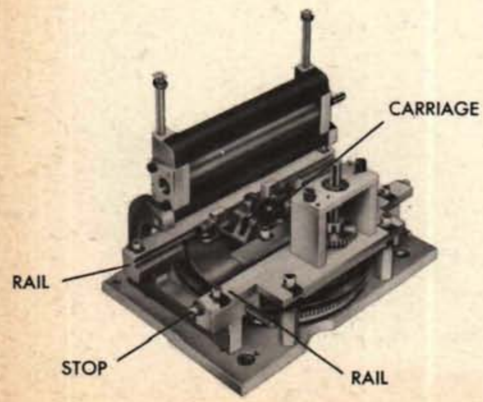


3 Wipe the roller, using a lint-free cloth moistened with solvent. Inspect the surface. *Spin* the roller to check for freedom of rotation.

4 If roller replacement or repair is necessary, remove the roller by taking out the adapter at the end opposite the shaft extension. Lightly tap the shaft extension end of the roller with a plastic hammer to start moving the adapter out of the roller bracket. Carefully *pry* the adapter out. Withdraw the roller through the adapter hole in the bracket.

5 Before removing the two balls, check for excessive lost motion between the balls and their guide rollers. Try to insert a 0.001-inch feeler gage between each roller and the ball. Do not force the feeler gage. The clearance between the rollers and the ball should be less than 0.001 inch. If the gage slips freely between the parts, the clearance must be reduced.

6 Remove the balls by tilting the unit while holding one hand over the carriage to catch the ball.



7 Remove the stop from one end of the carriage rail.

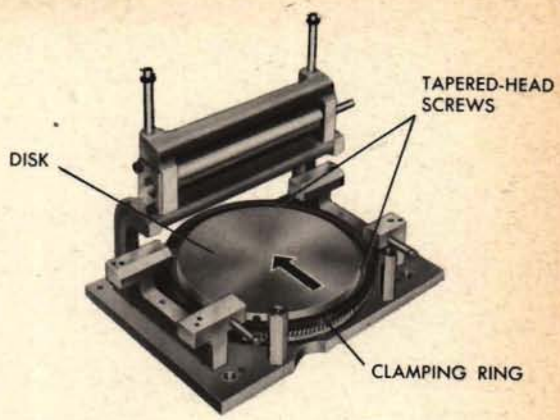
8 Slide out the carriage. Do not remove the carriage rack unless a new rack is required.

9 Remove the screws holding the rails, and tap the rails up to withdraw the dowels.

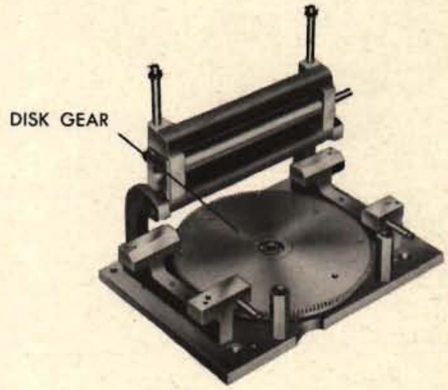
10 Wipe the disk clean with a lint-free cloth moistened with solvent. Inspect the disk surface. Do not remove the disk from the gear unless one is defective.

11 Remove the disk by taking out two of the special tapered-head screws that clamp the disk.

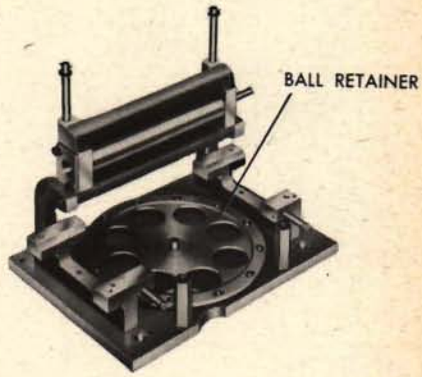
12 Slide the disk and clamping ring out toward the rear of the integrator.



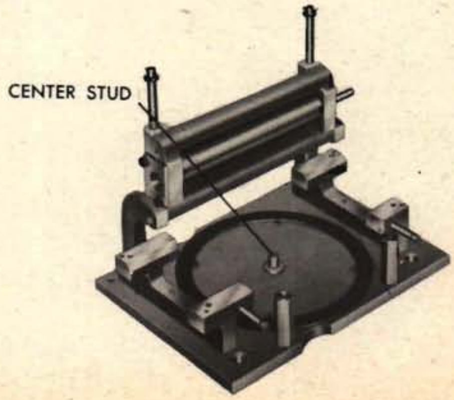
13 Lift off the disk spur-gear assembly.



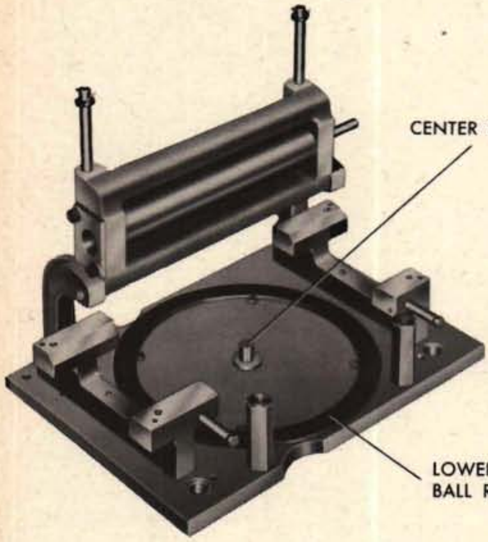
14 Lift the ball retainer off the center stud.



15 Do not remove the center stud unless a new stud is required.



Repairing the parts: four-inch unit


CENTER STUD
LOWER BALL RACE

Tightening the center stud

The center stud in a four-inch disk integrator is concentric. Inspect the stud to be sure it is tight. To tighten the stud, turn the plate upside down, rest the stud shoulder on a support, and tap the flanged end of the stud evenly into the countersink in the plate, using a light ball-peen hammer.

Replacing the center stud

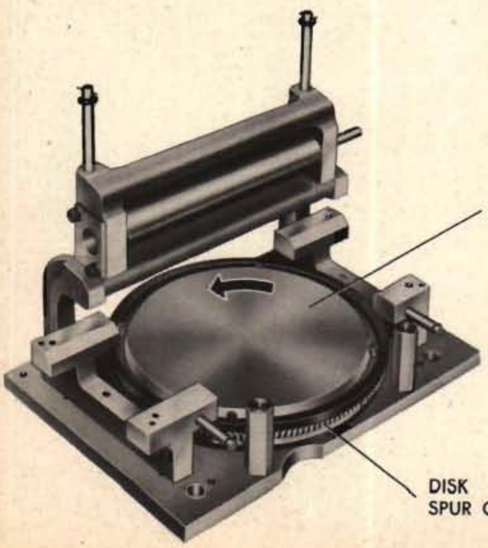
Use a center drill to remove the riveted flange of the old stud. Support the plate around the stud, and drive out the stud with a punch and hammer.

Polish the new stud to fit the center bearing and insert the stud in the plate hole. Support the stud shoulder, and tap the flanged lip into the countersink until it is flush with the plate. For a detailed explanation of removing and replacing parts riveted in this way, see pages 77-79.

BALL RETAINER

Repairing the ball retainer

(See page 294.)

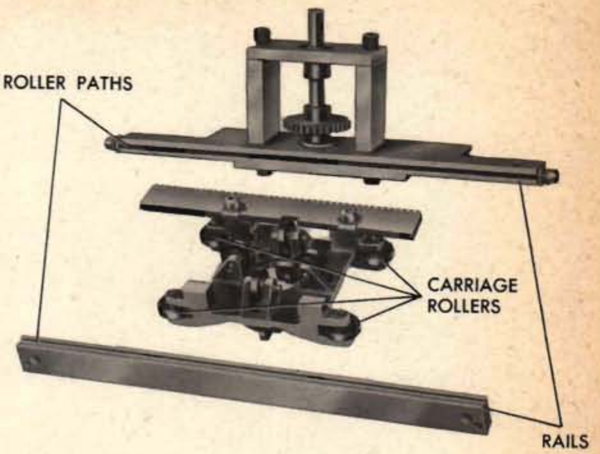

DISK
DISK SPUR GEAR

Repairing the disk

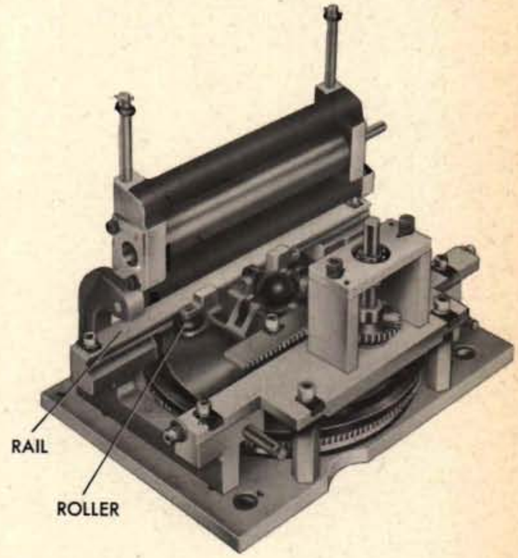
Rust or hair scratches may be smoothed by polishing the surface with crocus cloth and oil. Inspect the center of the disk. If any depressions are found here, the disk must be replaced. Place the disk on the gear, against the screws. Put on the ring and replace the four screws. Lubricate the ball race with grease and mount the gear on the stud. Turn the disk slowly to check freedom and smoothness of rotation. Spin the disk. If it does not spin to a gradual stop, look for jammed balls in the retainer, or a faulty center bearing.

Repairing the carriage rails

Wash the carriage rails and clean the roller paths with tissue. Remove any embedded material. Check the straightness of the roller paths. If the rails are bent, replace them.



Try the carriage on the rails to check the fit of the rollers on the roller paths. The rollers should have an up-and-down play of approximately 0.001 inch. Removing excessive lost motion here requires replacement of the worn parts. If necessary, polish rough or high spots by stroking the roller path with a steel bar wrapped in crocus cloth. Wash the rails thoroughly after completing this work.

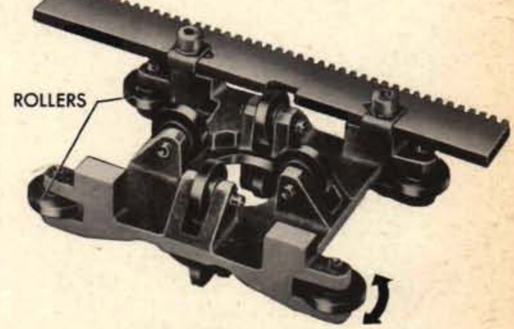


Repairing and replacing the carriage rollers

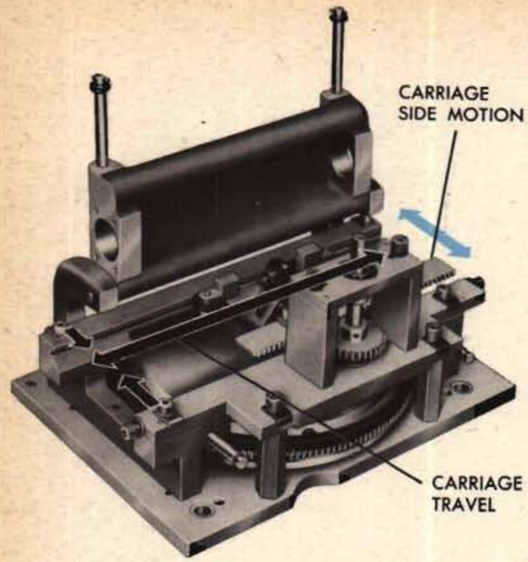
Wash all dirt and old lubricant from the carriage rollers with solvent. Check the rollers for smooth rotation. Rough or sticking rollers and rollers with grooves or other damage should be replaced.

All carriage rollers are mounted on small shafts having flared ends which hold the shafts in position. Never drive out a shaft without first filing one end to remove the flare.

Lubricate the new shaft and mount the roller and shaft on the carriage. Support the spread end of the shaft on a block. Using a center punch, flare the other end of the shaft to hold it in place. After flaring, make sure that the shaft has no play in its mounting.



TOP VIEW OF CARRIAGE AND ROLLERS



Reducing lost motion between the carriage and the rails

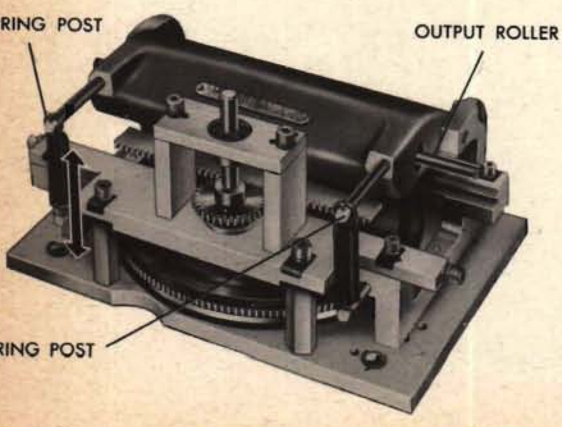
Mount the two rails and slide the carriage in place. Try the carriage in the rails for side play throughout its normal travel. On a new unit, the maximum side play is 0.001 inch. Excessive lost motion which is equal along the entire length of the rails can be corrected by moving the rails closer together. Remove the carriage and the rails. Drive the dowels out of both rails. Replace the rails and insert the rail screws, but do not tighten them. Replace the carriage. Both rails should then be positioned so that there is no excessive lost motion between them and the carriage. The rails must be aligned so that, as the carriage moves through its full travel, the centers of the balls move directly under the output roller axis and across the center of the disk.

To make this alignment, replace the balls, being careful not to drop them into the hole. Gently lower the output roller on its hinge until it touches the upper ball. Mount the springs. Position the rails so that, when the carriage is moved through its normal travel, the output roller moves up and down as little as possible. The maximum allowable movement is 0.020 inch. To measure up-and-down movement, use a dial indicator attached to the base with the pointer touching the end of one spring post.

REPLACING THE BALLS

At the same time make sure that the balls in the carriage roll over the center of the disk. When the carriage is centered and the disk is turned, there should be no motion of the output roller.

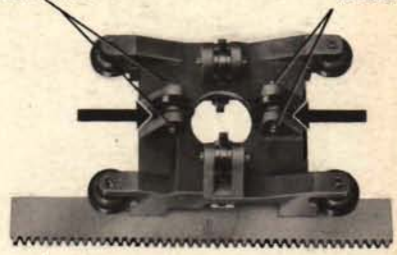
Side motion between the carriage and rails should not exceed 0.001 inch. After the carriage has been positioned correctly, tighten the screws. Remove the carriage and redowel the rails. Use oversize dowels or drill new dowel holes.



Reducing lost motion between the balls and ball guide rollers

Excessive lost motion between the balls and their guide rollers may sometimes be eliminated by replacing the rollers. On a new unit this lost motion does not exceed 0.001 inch, but through use and lack of lubrication these rollers may have developed side play.

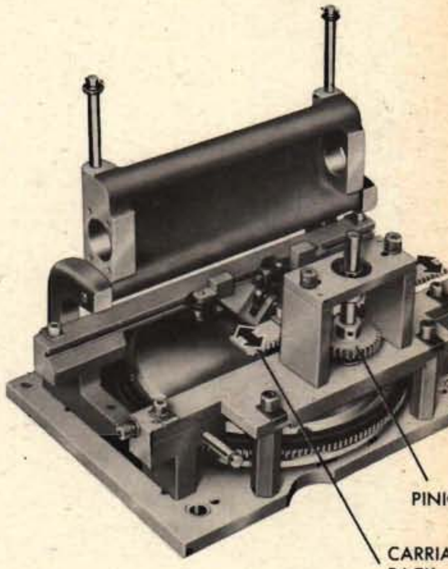
If changing the rollers does not reduce excessive lost motion sufficiently, a second method may be employed: repositioning the roller shaft. THIS METHOD SHOULD BE USED ONLY IN EMERGENCIES, HOWEVER, AND EVEN THEN ONLY AS A TEMPORARY REPAIR UNTIL A REPLACEMENT CARRIAGE ASSEMBLY IS AVAILABLE.



Repositioning a roller shaft

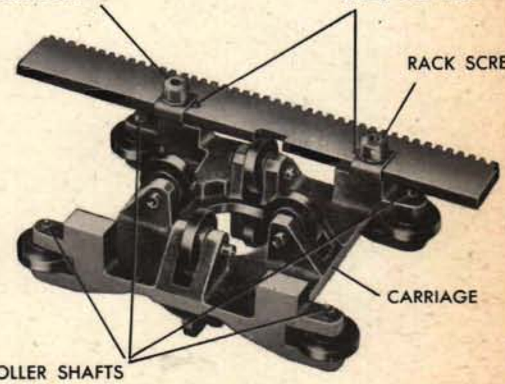
When it is necessary to move the shafts to decrease lost motion, both shafts must be moved equal distances to maintain the vertical alignment of the balls.

Remove the carriage from the rails. Remove the roller by driving out the shaft with a punch. Using a rat-tail or needle file, make the shaft hole slightly oval by filing the side toward the center of the carriage. Replace the roller and shaft and mount the carriage in the rails. Put in the balls, press the shaft toward the balls, and check for lost motion. When one half the lost motion has been eliminated, stake metal into the hole to hold the shaft in its new position closer to the ball. Secure the shaft in position by flaring its ends with a center punch. Reposition the opposite shaft in the same manner, eliminating the remainder of the excess lost motion.

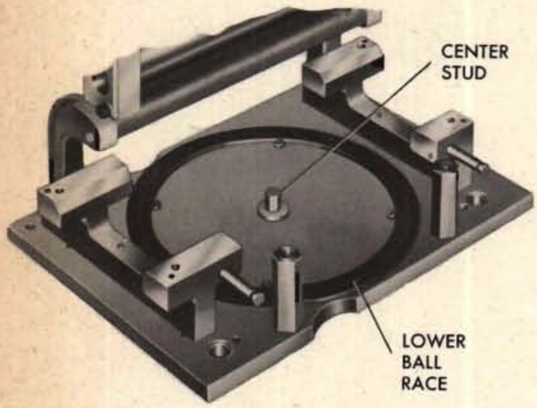


Positioning the carriage rack

Before positioning the carriage rack for proper mesh with the input pinion, the lost motion between the carriage and the rails must be checked and, if necessary, reduced. The carriage rack should then be positioned. To do this, remove the rack from the carriage and drive out the old dowels. Replace the rack on the carriage and position the rack until the correct mesh is obtained throughout the carriage travel. Tighten the screws. Remove the carriage with the rack in its new position, and redowel the rack, using oversize dowels in the old dowel holes. Wash the carriage and put a drop of lubricating oil on each roller shaft. Slide the carriage into the rails and recheck the carriage rack mesh.



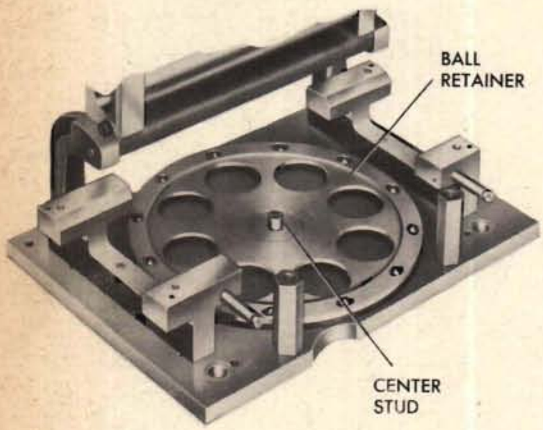
Reassembling the four-inch unit



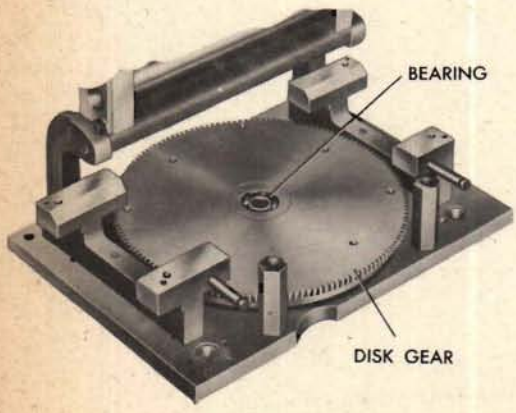
Wash all the parts in an approved solvent and dry them before beginning reassembly. Put a drop of oil in each bearing.

1 Check the tightness of the center stud.

2 Inspect the upper and lower ball races for rust or scratches. Hair scratches or rust spots may be smoothed by polishing. Wash the surfaces thoroughly in solvent after polishing. Cover the races with a thin film of grease before replacing the ball retainer.



3 Replace the ball retainer on the center stud.



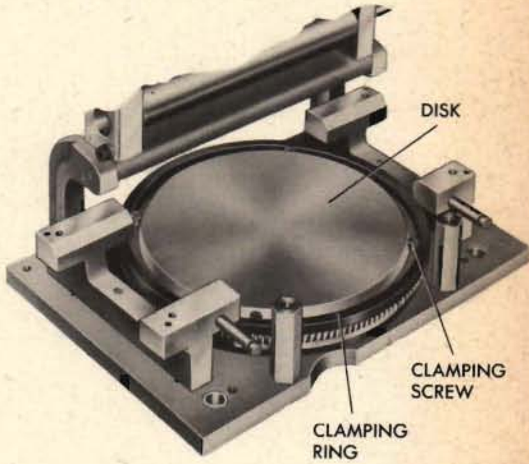
4 Replace the bearing on the center stud above the retainer.

5 Replace the disk spur gear on the center stud bearing.

6 Replace the disk and disk clamping ring together. Handle the disk only on the edges, never on the faces, because perspiration in the pores of fingers is sufficient to start corrosion of the disk. Wipe the surface with a lint-free cloth to prevent scratching the polished surface. Coat the underside with a film of grease.

7 Tighten the four screws on the clamping ring to secure the disk. Make sure that the disk is tightly in place when the clamp is tight.

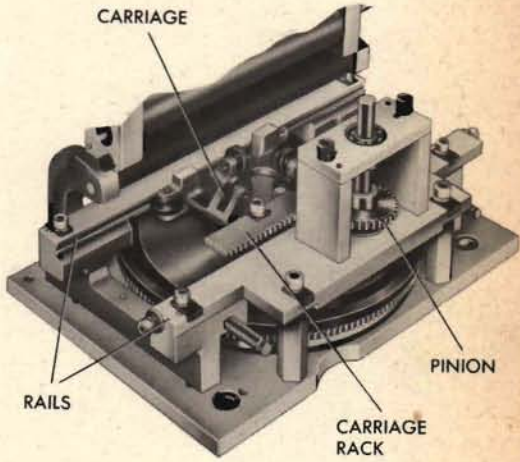
8 Coat the disk with a thin film of grease. Turn the disk gear slowly to check for freedom and smoothness of rotation. Spin the disk. It should spin to a gradual stop.



9 Mount and adjust the rails.

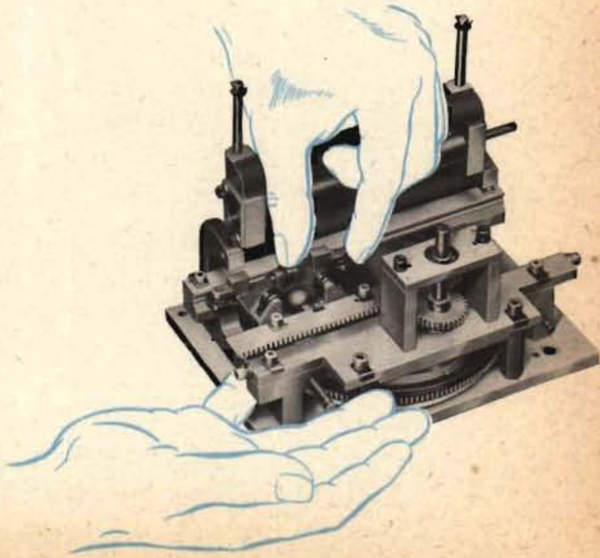
10 Slide in the carriage.

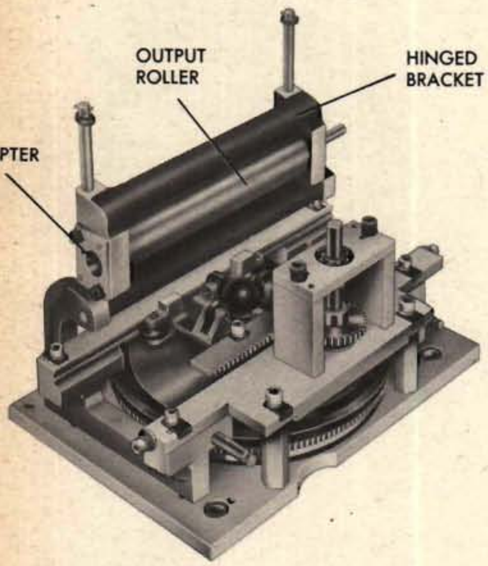
11 Check the carriage rack and pinion mesh, and the freedom of the carriage in the rails.



12 Slip one finger between the carriage and disk so that it reaches the hole. Drop the lower ball on the finger and set the upper ball on top of the lower one. Slowly remove the finger so that the lower ball makes contact with the disk. Failure to follow this procedure may result in denting the disk.

13 Insert a feeler gage between the upper ball and each guide roller to make sure that the clearance is not more than 0.001 inch.





14 If the output roller was removed, mount it and one of its bearings in the hinged bracket.

15 Mount the adapter containing the other bearing for the output roller.

16 Spin the roller to check for smoothness of operation.

17 Spread a thin layer of grease on the roller.

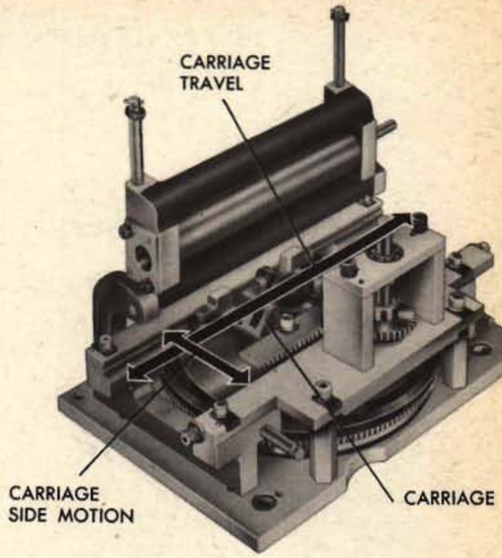
18 Lower the hinged bracket into position.

19 Hook one hold-down spring over the lower spring post. Pass a loop of strong cord through the upper spring loop and raise the spring until it can be hooked over the upper spring post. Install the second spring in the same manner.

20 Move the carriage through its travel and turn the disk to check the unit for smooth operation.

Bench checking the unit

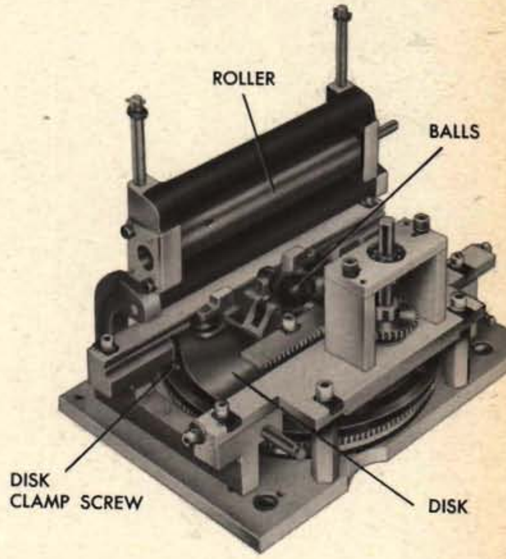
Before reinstalling the unit, check the assembly of the unit against the assembly drawing. See also that the following requirements are met:



1 The clearance between the balls and the rollers should be less than 0.001 inch.

2 The side motion of the carriage between the rails should not exceed 0.001 inch.

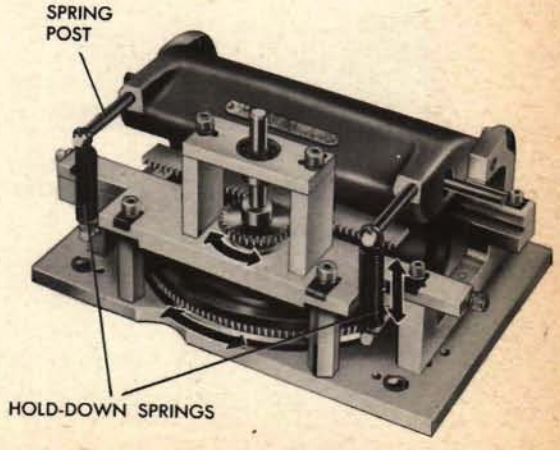
3 The carriage should move freely through its normal travel.



4 The clamp screws should be sufficiently tight to prevent the disk from slipping on the spur gear.

5 The balls, roller, and disk should be free of marks, flats, or scratches.

6 Be sure that a thin coating of grease has been applied to the disk and roller, and that the bearings have been oiled.

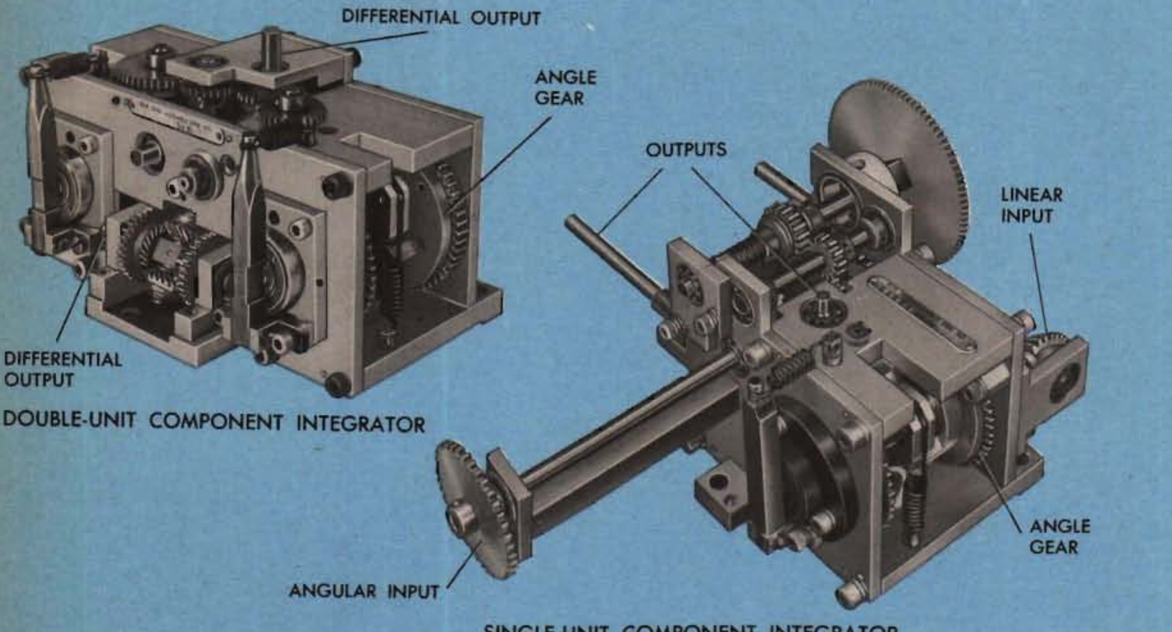


7 Measure the hold-down spring tension by attaching a spring scale to one upper spring post. The required spring tension is 5.5 pounds $\pm 10\%$.

8 Use an indicator to make sure that the up-and-down movement of an upper spring post does not exceed 0.020, when the carriage is run through its full travel.

9 Both inputs should turn freely when the unit is held in various positions.

COMPONENT INTEGRATORS



DOUBLE-UNIT COMPONENT INTEGRATOR

SINGLE-UNIT COMPONENT INTEGRATOR

Component integrators are mounted singly or in pairs. An integrator mounted alone is a single-unit component integrator. A double-unit component integrator consists of two single integrators and two differentials in one mounting.

A component integrator has two inputs and two outputs. The two outputs are carried by two roller shafts. The linear input is carried by the roller shaft mounted on the angle gear. The other input positions the angle gear. Driving friction is provided by two spring-loaded pressure rollers which press a ball against the input and output rollers.

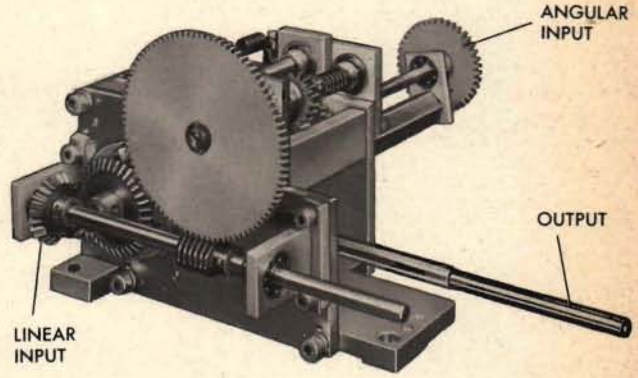
In a single-unit, the outputs are connected directly with the instrument.

In a double-unit, one output of each integrator is an input to one of the differentials. The other two outputs are the inputs to the second differential.

Single and double-unit integrators are self-contained units, mounted between two pairs of parallel plates. A complete unit can usually be removed by loosening the screws holding the bottom plate, although some adjacent gearing and mechanisms may have to be taken out first. If the unit must be removed for repair or replacement, consult the instrument OP for instructions.

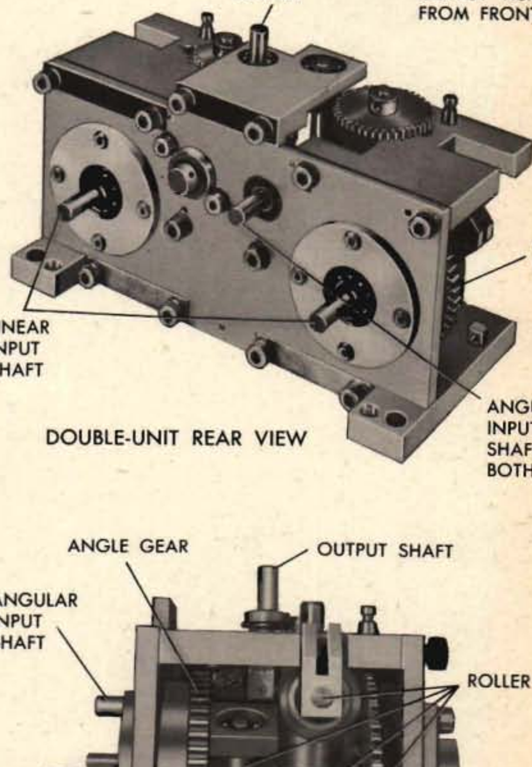
Typical symptoms

If a test analysis and the unit check tests show an integrator is not operating normally, look for the following symptoms:



SINGLE-UNIT REAR VIEW

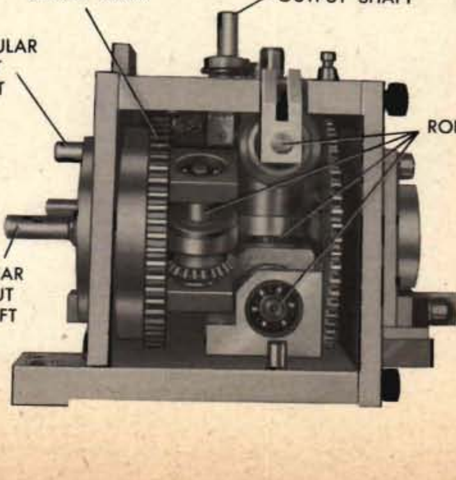
JAMMING: The linear input shaft or the angular input shaft cannot be turned by hand.



DOUBLE-UNIT REAR VIEW

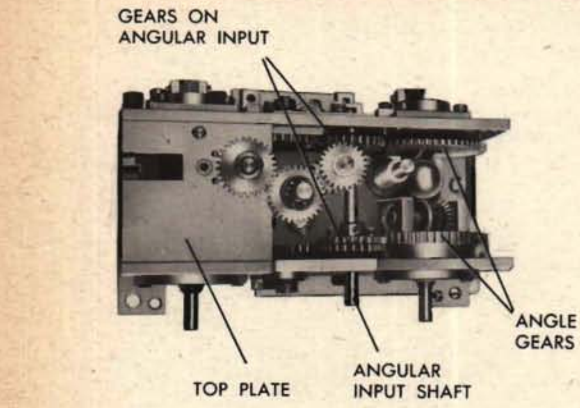
STICKING: The linear input shaft or the angular input shaft resists turning past a certain point or points, or turns sluggishly. (Component integrator lines normally turn more stiffly than other shaft lines because the balls and rollers are under spring pressure.)

EXCESSIVE LOST MOTION: There is too great a lag between the turning of the linear input shaft and the output shafts, or between the angular input shaft and the angle gear; or the end play in the roller shafts is excessive.



SLIPPING: Turning the linear input shaft turns the output shafts only intermittently, or not at all. (The unit is designed to produce no output when only the angular input is turned.)

Locating the cause

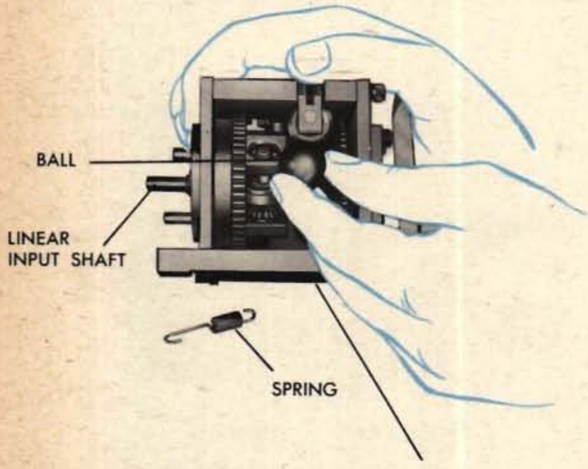


DOUBLE-UNIT–PLATE REMOVED

Jamming and sticking

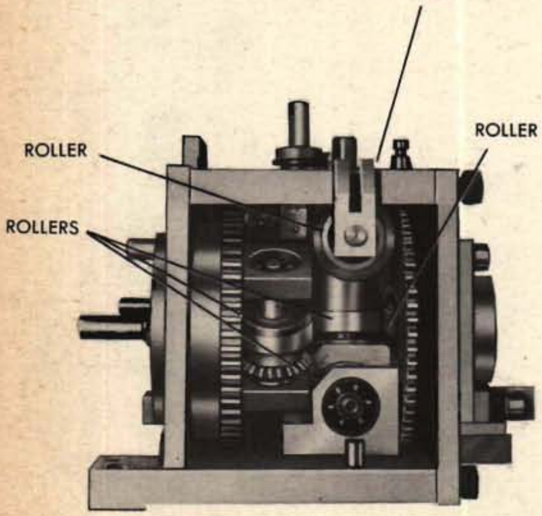
If the angular input shaft jams or sticks, inspect, for dirt or damage, the two spur gears on the shaft and the two angle gears with which they mesh. These gears can sometimes be cleaned in place, but if one needs to be replaced, the integrator must be removed and disassembled.

If the linear input shaft will not turn or tends to stick, look for dirt or damage in the integrator bevel gears and the output gears which mesh with the differentials. These gears can sometimes be cleaned in position but must be removed for replacement.



DOUBLE-UNIT–SPRING REMOVED

If the linear input shaft is jammed but all the gears are clean and undamaged, the trouble may be due to dirt or damage on the surface of a roller or ball, or to a dirty or damaged bearing which supports one of the rollers. In order to locate the source of trouble, unhook the springs and lift out and examine the ball.



If the ball is damaged, one or more of the rollers probably is damaged too. The input and output rollers must be precision-ground to the diameter given on the assembly drawing, and for this reason should be replaced in case of damage. A damaged ball should be replaced for the same reason.

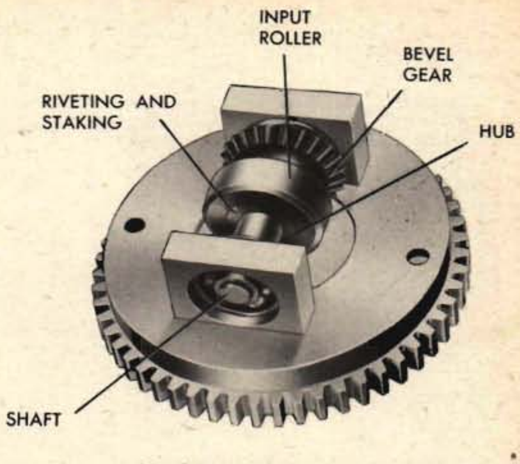
To locate faulty bearings, try to turn each roller by hand. If a roller will not turn, one of its bearings probably is dirty or damaged and should be cleaned or replaced. To clean or replace such a bearing, the roller must be removed.

Excessive lost motion

Excessive lost motion may be caused by worn gears, shaft end play, and, in the double unit, by worn differential gear teeth.

Inspect all gears for wear, and replace any that are worn enough to cause excessive lost motion. The unit must be disassembled in order to replace these gears.

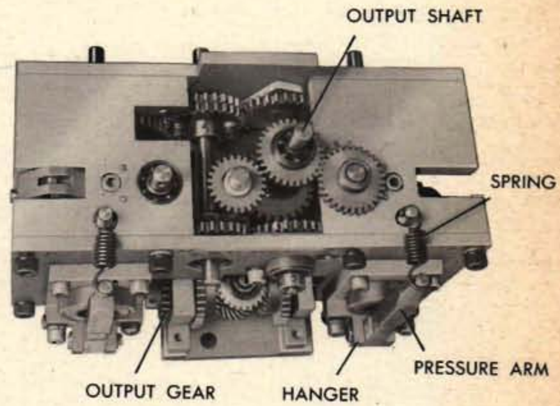
Examine each roller shaft for excessive end shake. If it exceeds the allowable maximum, the spacers on that shaft may be worn or may have been incorrectly reassembled. To replace a spacer, the unit must be at least partially disassembled.



A DOUBLE-UNIT ANGLE GEAR

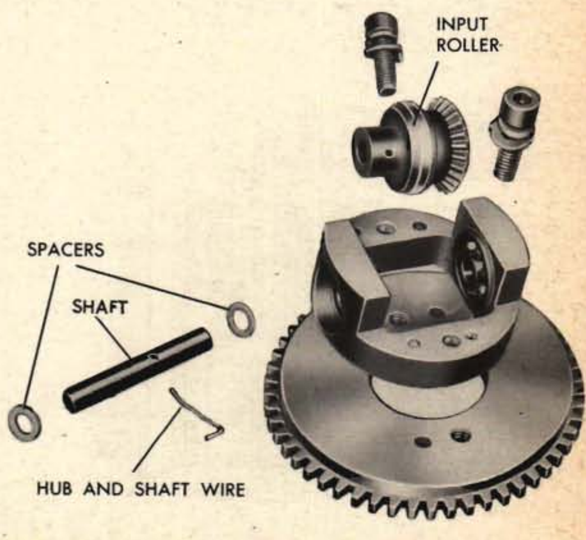
Slipping

If the output shafts slip when the linear input shaft is turning and the angular input shaft is in such a position that both outputs should turn, the cause may be insufficient friction due to stretched or broken springs, or a pressure arm frozen in its hanger. Springs and pivots can be disassembled for repair or replacement without disassembly of the unit.



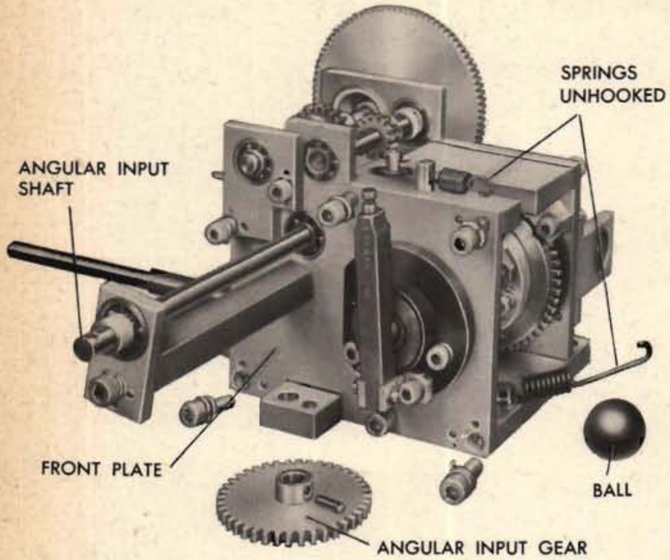
If the input roller does not turn when the linear input shaft is turning, look for a missing bevel-gear pin, a missing hub and shaft wire, or a roller slipping on its hub. If a roller slips on its hub, the riveting and staking is not holding.

In order to repair a gear, replace a wire, or rivet and stake a roller to a hub, the unit must be disassembled. To rivet a roller to a hub, refer to pages 77 and 79.



A SINGLE-UNIT ANGLE GEAR

Disassembling a single-unit



The single-unit component integrator described and illustrated in this chapter is from the Dummy Director Mk 1 Mod 3.

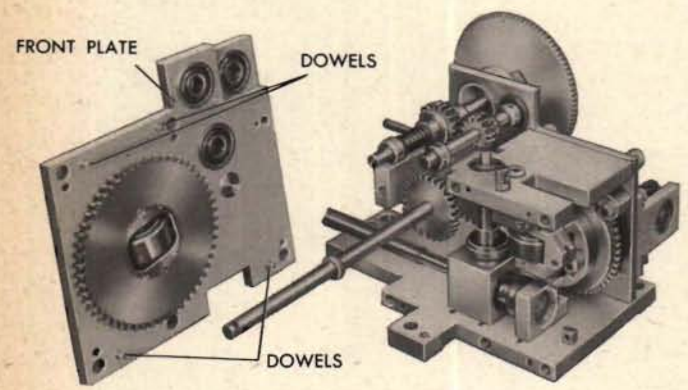
In disassembling a component integrator, be sure to tag all spacers.

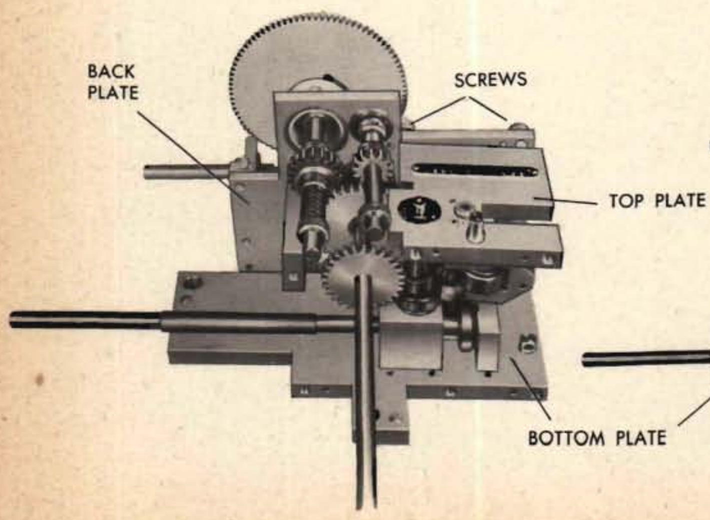
1 Use several loops of strong twine to unhook both springs. Remove the ball. Remove the gear from the angular input shaft.

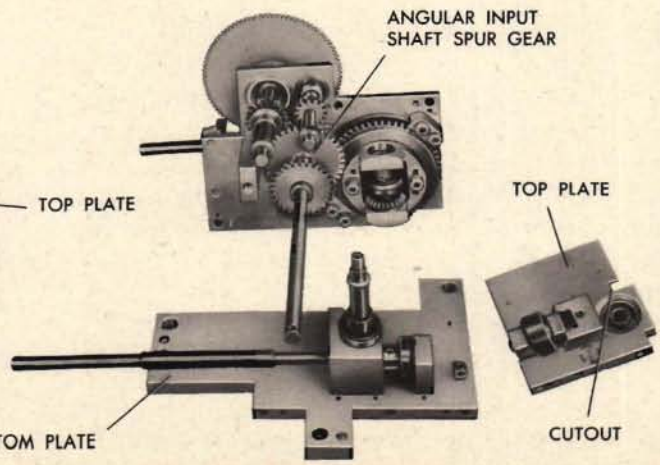
2 Unscrew the five No. 10 screws and one No. 8 screw and lift off the front plate. (Be careful not to bend the dowels.)

3 Unscrew the four No. 10 screws from the back plate.

4 In order to avoid bending the dowels, pull the top plate and the bottom, or mounting, plate away from the back plate simultaneously. (Carefully tap and pry the plates if necessary, and do not allow the spur gear on the angular input shaft to jam in the cutout portion of the top plate.)

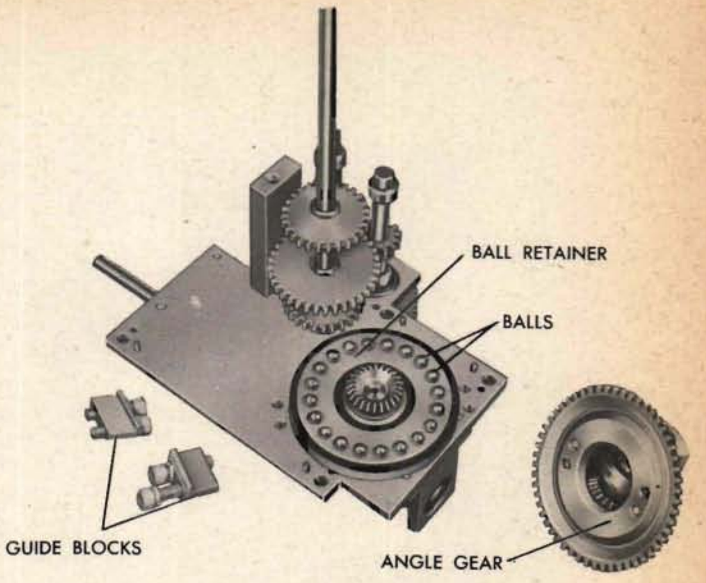






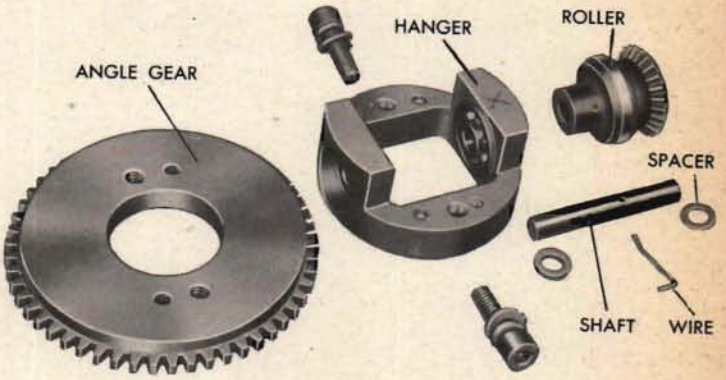
5 Remove the guide blocks and lift off the angle gear.

6 Lift off the ball retainer, being careful not to lose any of the balls.



7 Loosen the two No. 8 screws which hold the hanger of the input roller shaft to the angle gear. Carefully lift off the doweled hanger.

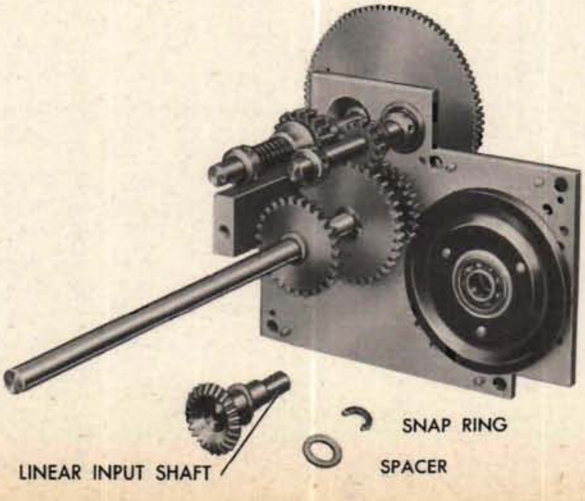
8 Mark the gear end of the hanger and note the position of the spacers. Then pull out the wire and push out the shaft.

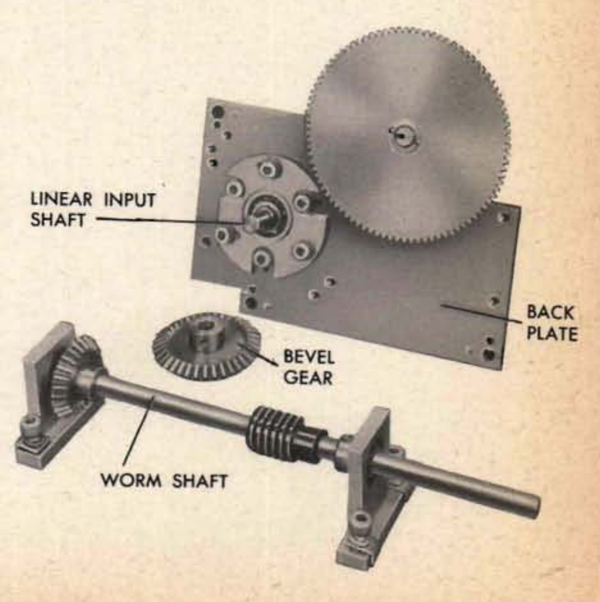


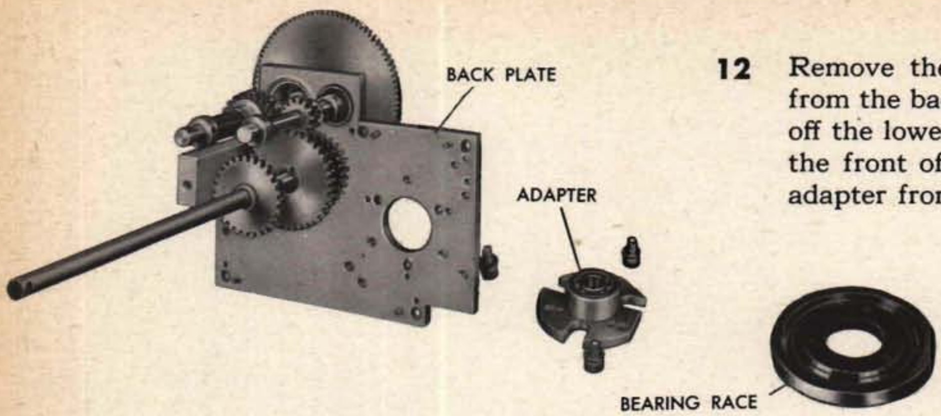
9 Loosen the four No. 8 screws and remove the hangers and worm shaft from the rear of the back plate.

10 Unpin and remove the bevel gear from the linear input shaft.

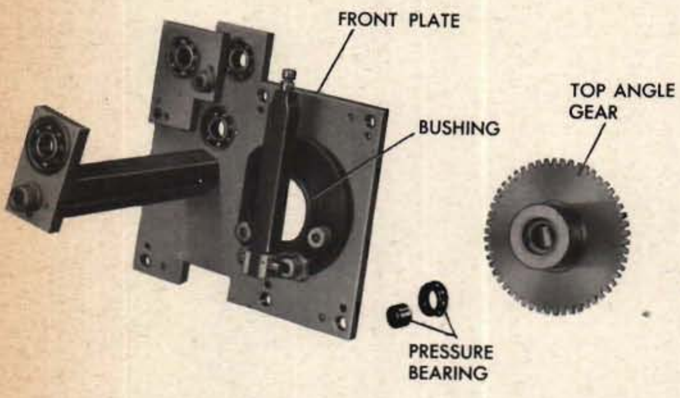
11 Remove the snap ring and pull out the linear input shaft.





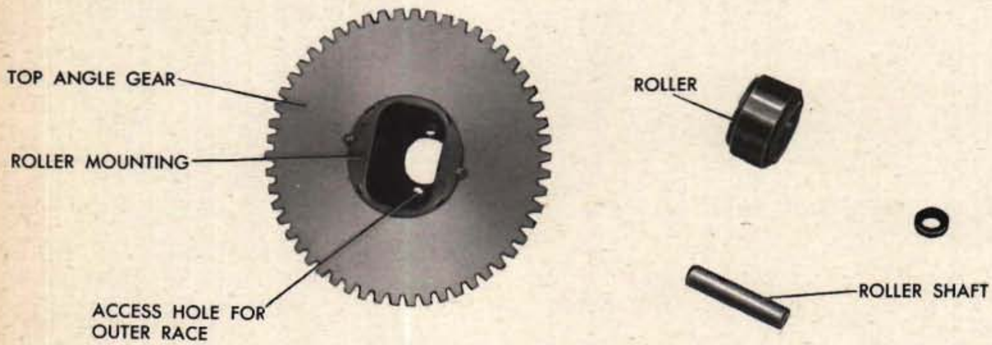


12 Remove the six No. 8 screws from the back of the plate. Lift off the lower bearing race from the front of the plate and the adapter from the back.

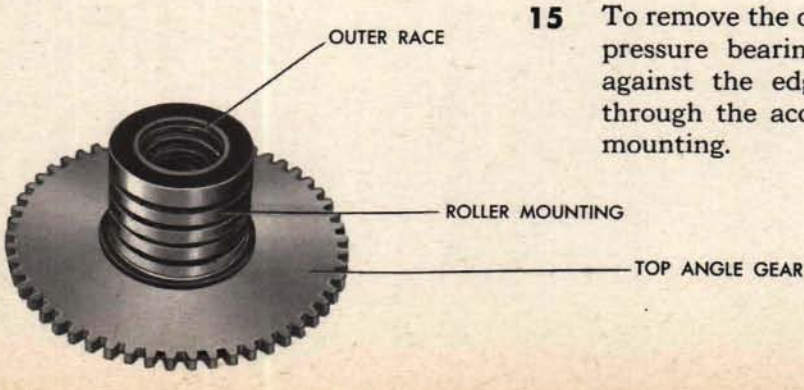


13 Pull the top angle gear and guide roller out of the bushing in the front plate. Remove the inner race and the ball retainer of the pressure bearing.

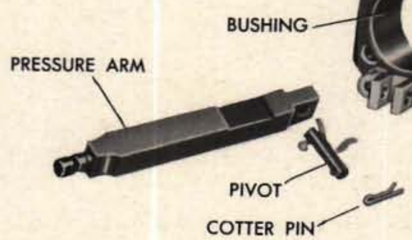
14 To remove the top guide roller from its mounting on the angle gear, drive out the shaft, and lift out the roller. Tag the spacers.

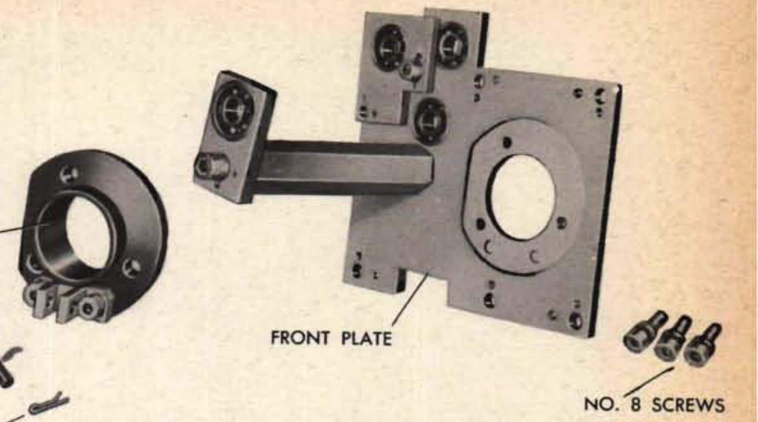


15 To remove the outer race of the pressure bearing, push a rod against the edge of the race through the access hole in the mounting.



16 Loosen the three No. 8 screws and lift the bushing off the front plate. Remove the cotter pin and pull out the pivot in order to remove the pressure arm.

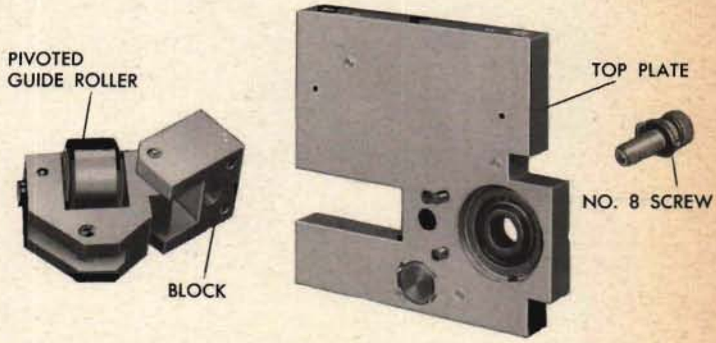


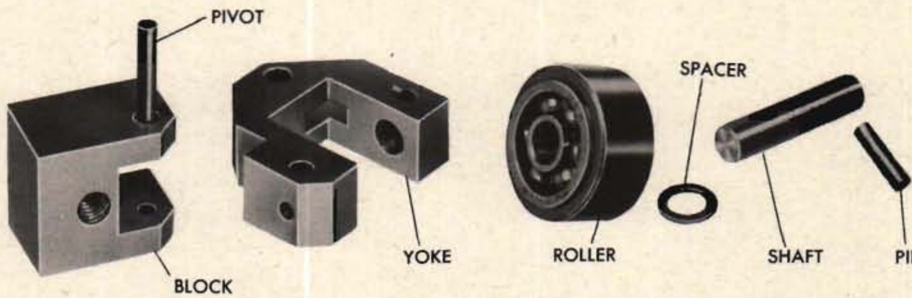


17 To remove the pivoted guide roller from the top plate, unscrew the No. 8 screw and pull the block off the dowels.

18 Separate the yoke from the block by driving out the pivot which is staked.

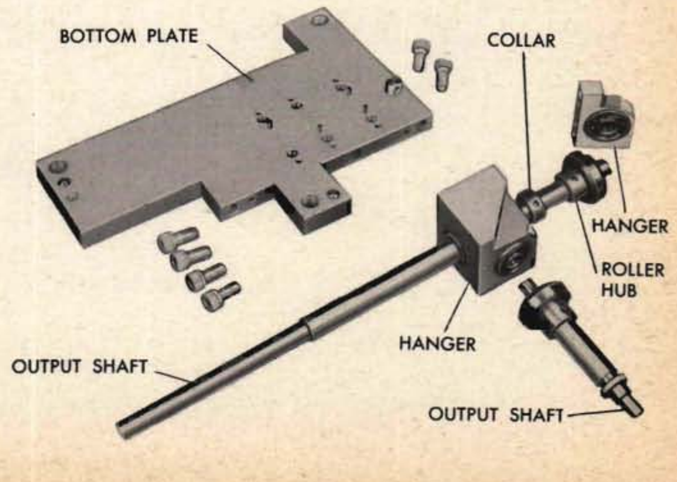
19 To remove the roller from the yoke, drive out the pin holding the shaft and push out the shaft.



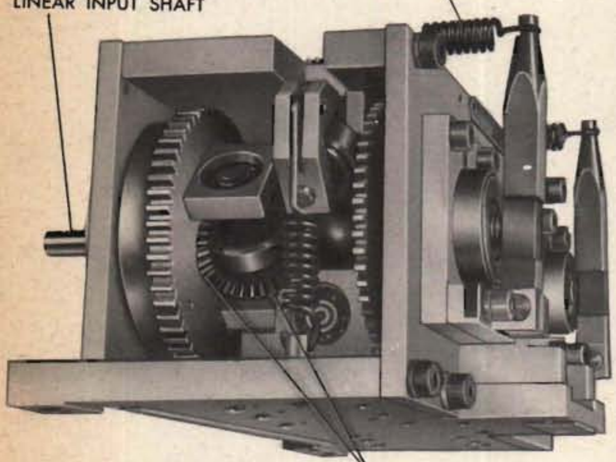


20 To remove the output shafts and hangers from the bottom plate, unscrew the six No. 8 screws.

21 Drive the pins out of the collar and roller hub on one output shaft. Separate the shafts from the hanger.



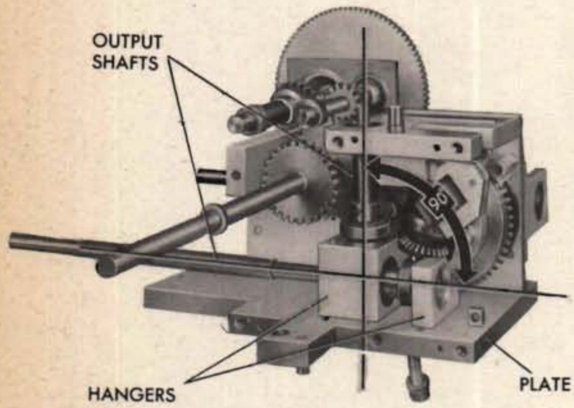
Repairing the parts



Replacing or repinning a bevel gear

If a new bevel gear is to be mounted on the input roller shaft, or a missing bevel-gear pin replaced, assemble the entire unit, holding the parts in place with set screws. Apply spring tension and examine the bevel gears for correct mesh. Then disassemble the unit and pin the gear.

Clean all gears before reassembling the unit.



SINGLE-UNIT—FRONT REMOVED

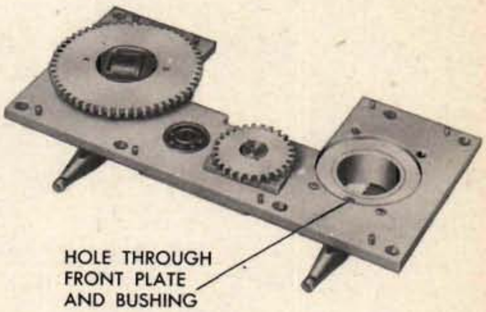
Positioning new output shaft hangers

The output shafts must be positioned precisely at 90° to each other in order to give the correct output. Drive out the old dowels in the plate, mount the new hanger on the plate and then reassemble the entire unit. Shift the hangers in the screw clearance holes until the shafts are square and parallel to the edges of the plates. If the shafts are square with respect to the plates, they can be assumed to be square to each other. Tighten the hanger screws; disassemble the unit, and dowel the hangers with oversize dowels. Turn to pages 74-75 for instructions on doweling.

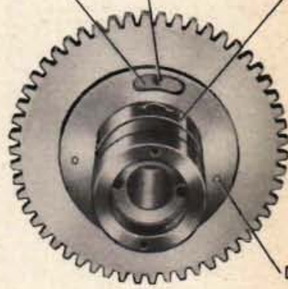
Replacing or repinning angular input gearing

The axis of the guide roller in the top angle gear must be parallel to the axis of the linear input roller for smooth operation.

If a new angle gear is to be installed in the single-unit integrator, one of the gears meshing with the angle gears may have to be repositioned to make the roller axes parallel. To reposition a gear on the angular input shaft, assemble the entire unit and make the setting between the two roller axes, holding the gear in position with a set screw. Disassemble the unit and pin the gear.



To replace the upper roller mounting in the double-unit, assemble the roller in the mounting and the mounting on the angle gear. Fasten the mounting with the two screws. Then reassemble the unit according to the procedure on pages 337-341. Make the roller axis exactly parallel to the input roller axis by turning the mounting within the limits provided by the slotted holes. Access to the screws is through the holes in the bushing and front plate. Disassemble the unit and dowel the mounting and gear together.

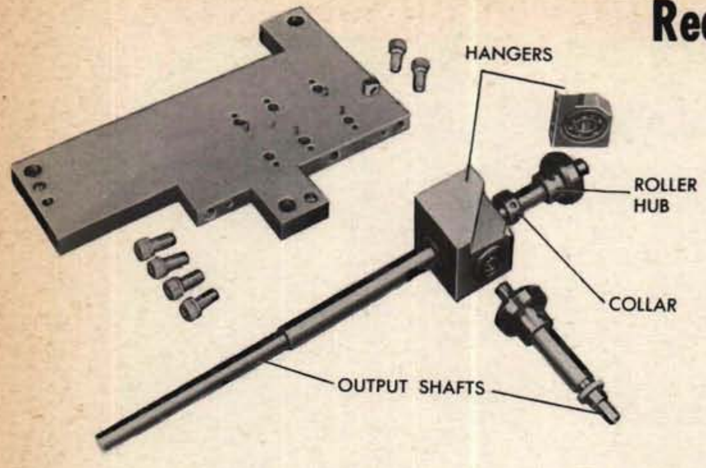


In a double-unit, if the adjustable gears on the angular input shaft, S2, must be replaced, the angular relationship between the two units must be reset, as well as the parallelism of the guide rollers to the input rollers. Mount the gears on the shaft and then reassemble the unit according to the procedure on pages 337-341. Refine the angular relationship between the angular input gears to meet the requirements of bench check 3. Tighten the set screw in the gear hub. Tighten the screws holding the gears together. Disassemble the unit and pin the replacement parts.

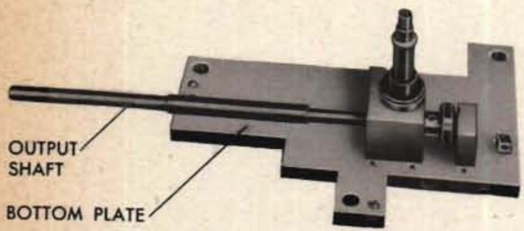
Replacing a ball or a roller

All damaged balls and rollers should be replaced. Bearings should be assembled in the rollers with a light press fit. Balls, rollers and bearings should be cleaned and lubricated before final reassembly.

Reassembling the single-unit

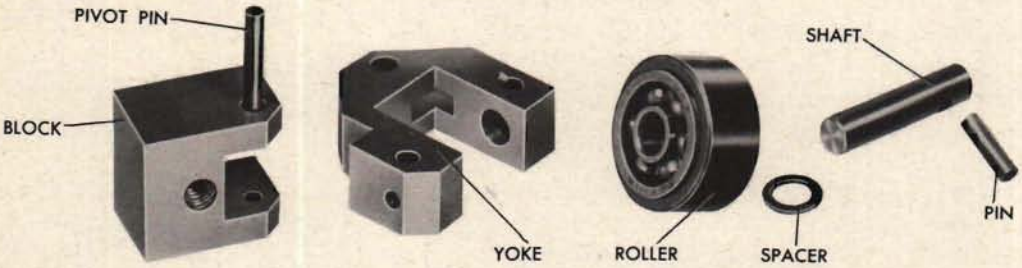


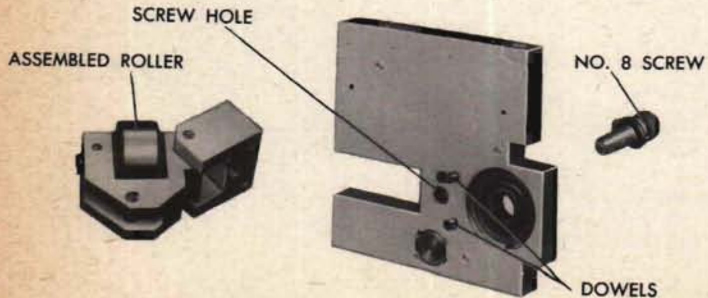
1 Mount the output shafts in the hangers. Repin the collar and roller hub.



2 Assemble the output shaft hangers on the bottom plate.

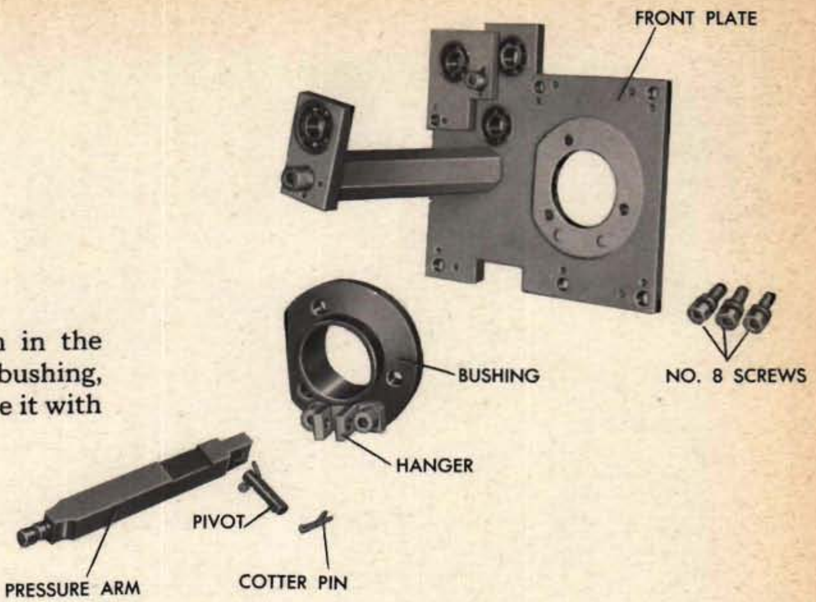
3 To mount the roller in the yoke, hold the roller and the spacers in position and push the shaft in. Pin the shaft, and stake the pin.





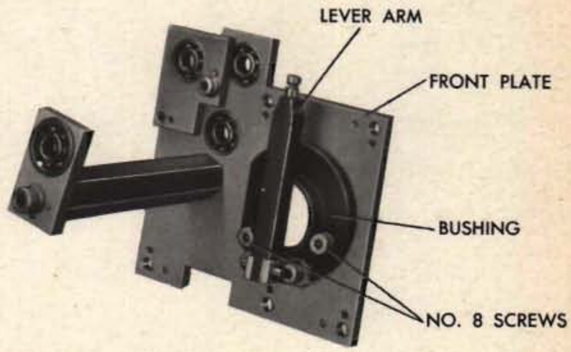
4 Mount the yoke in the block, push in the pivot pin and stake it at both ends.

5 Mount the block on the dowels in the top plate and fasten it in place with a No. 8 screw.

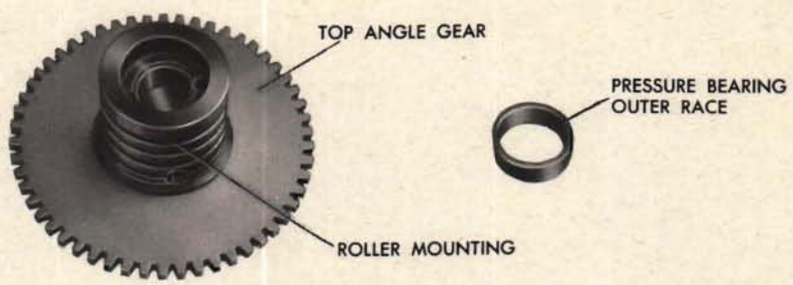


6 Mount the pressure arm in the hanger attached to the bushing, insert the pivot, and secure it with cotter pins.

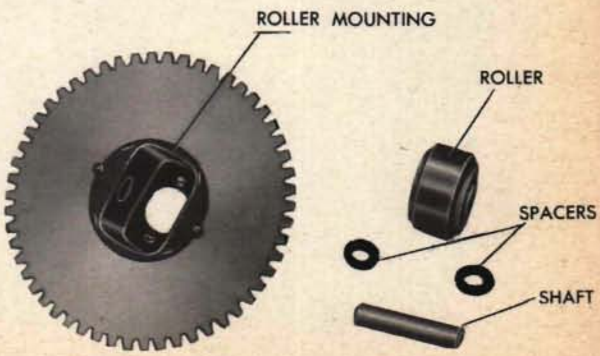
7 Slide the bushing into the hole in the plate, with the lever arm in the position shown, and tighten the three No. 8 screws.

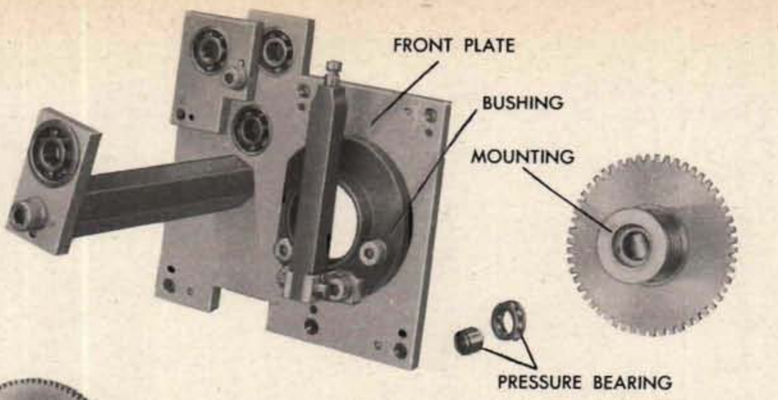


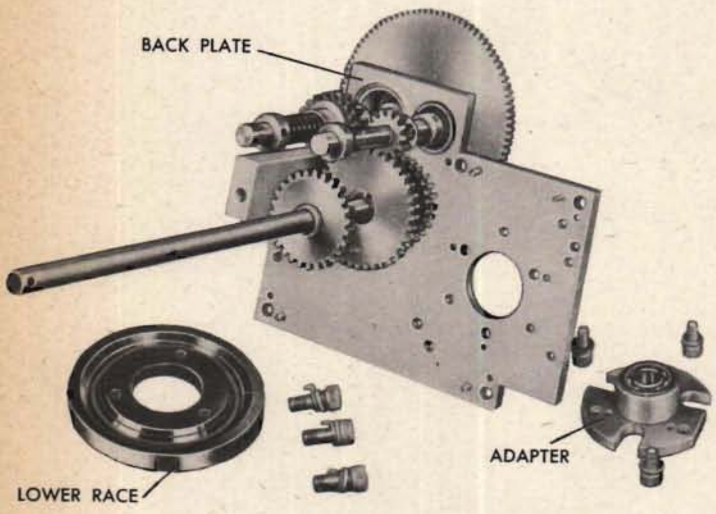
8 Push the outer race of the pressure bearing into the roller mounting riveted to the top angle gear.



9 Place the roller and spacers in the mounting. Insert the shaft and stake it at both ends.





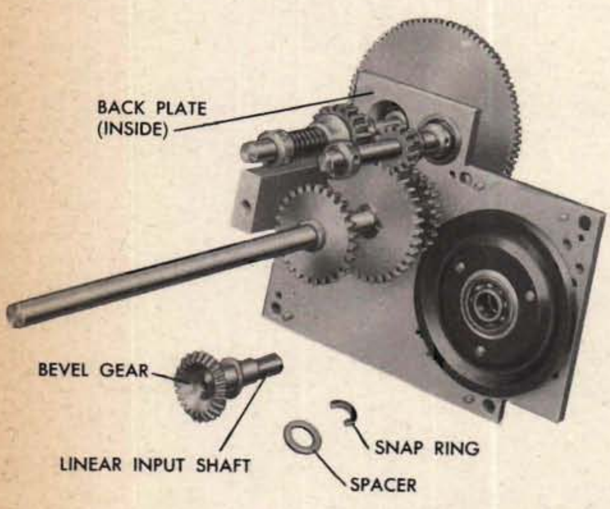


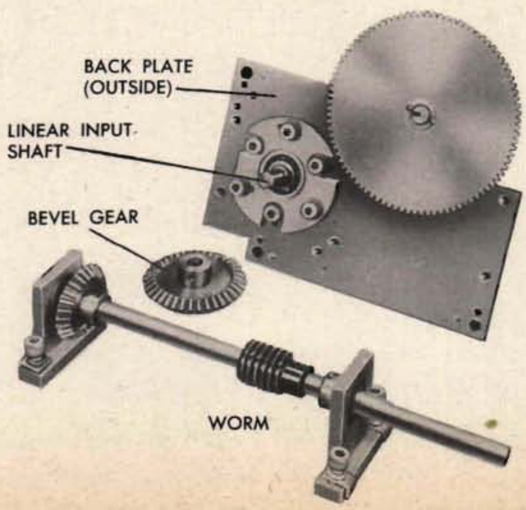
10 Slide the mounting into the bushing in the front plate and replace the pressure bearing.

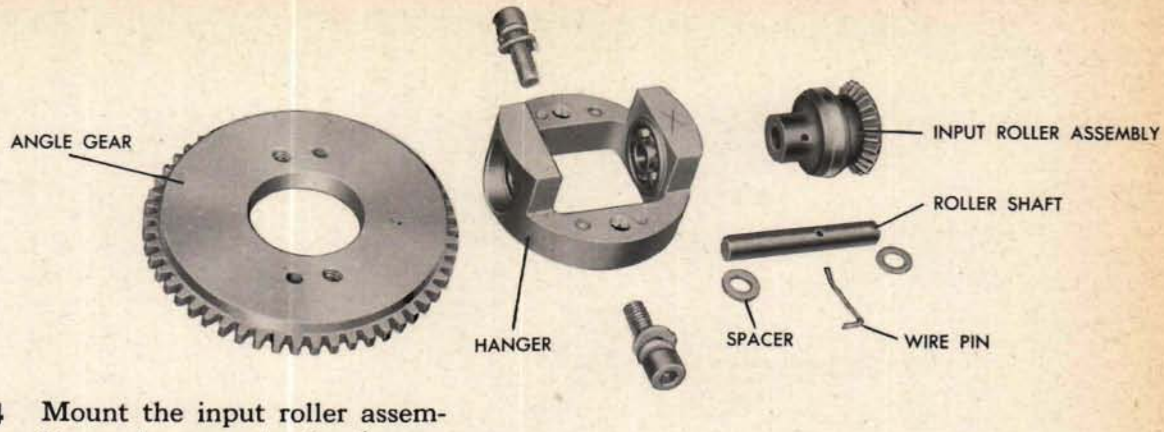
11 Place the adapter in the plate and the lower race on the plate at the same time. Then, holding the parts in position, tighten the six No. 8 screws.

12 Mount the linear input shaft in its adapter, and secure it in place with the spacer and snap ring.

13 Mount the bevel gear on the linear input shaft, seating the taper pin with hand pressure only. Mount the worm shaft; test the meshes and seat the taper pin if the mesh is satisfactory.







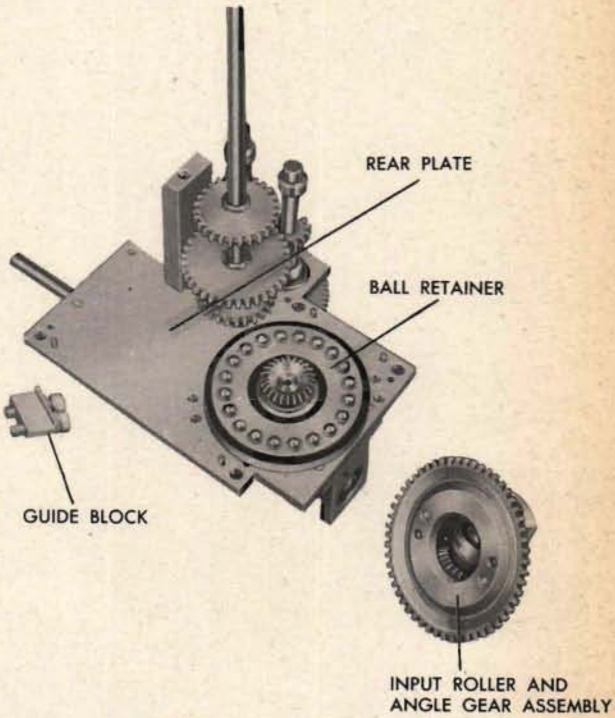
14 Mount the input roller assembly and spacers in the hanger with the gear toward the marked end.

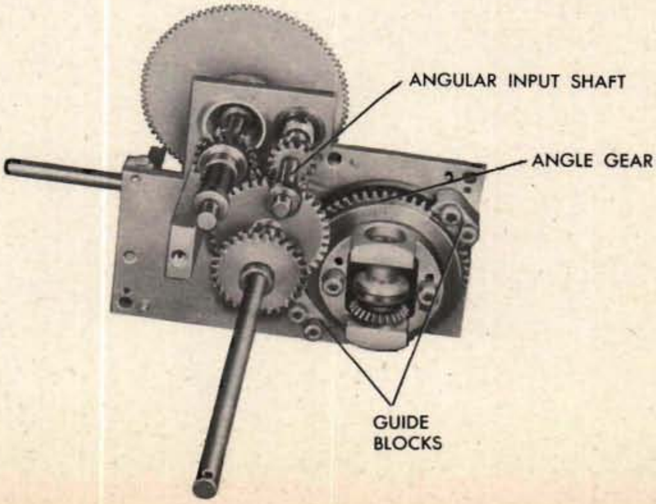
15 Push the shaft in place and secure it with the wire pin.

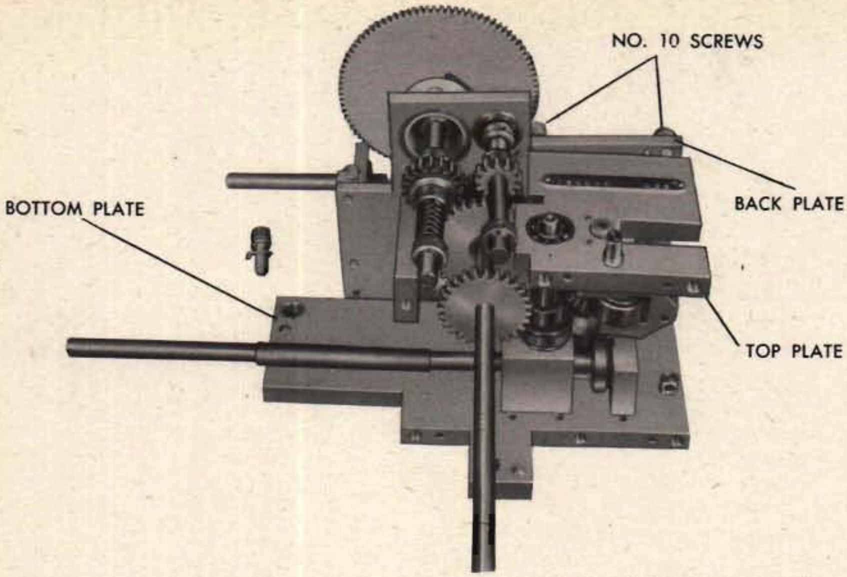
16 Mount the hanger carefully on the angle gear and fasten it with the screws.

17 Mount the ball retainer on the lower race and drop the balls in place. Lubricate the balls and races with an approved lubricant.

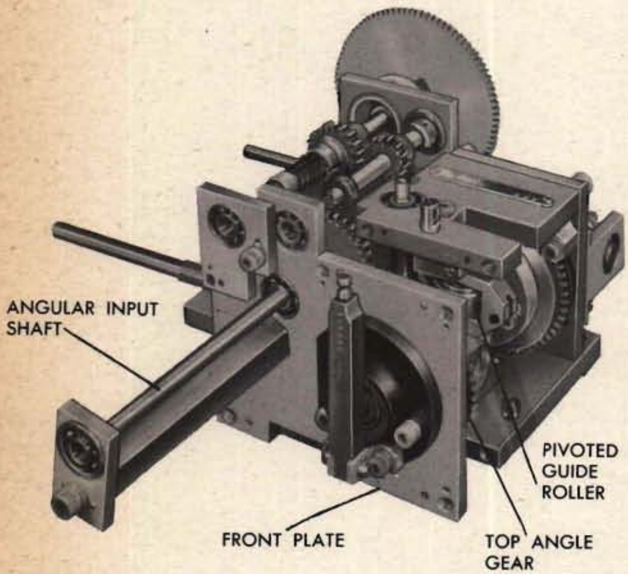
18 Place the angle gear assembly over the balls and fasten the guide blocks. Be sure to mesh the marked tooth of the angle gear with the marked tooth of the gear on the angular input shaft.





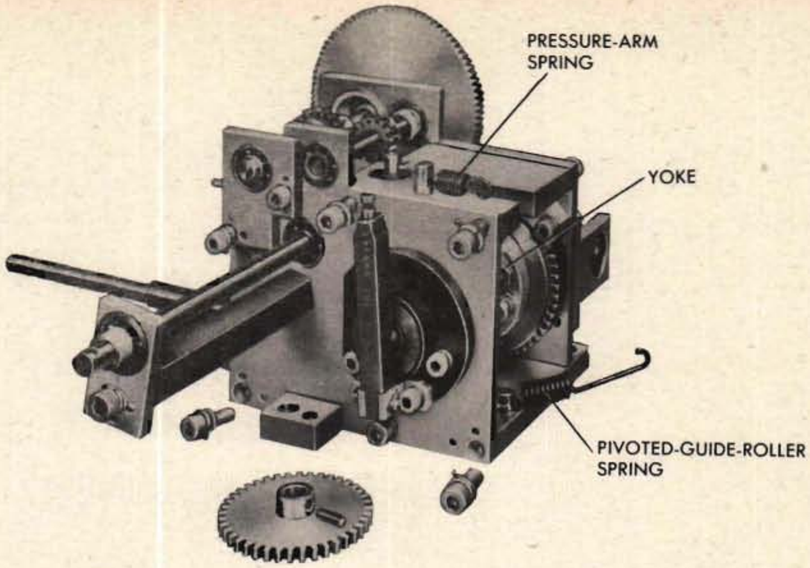


19 Simultaneously position the top and bottom plates on the back plate and fasten them with the four No. 10 screws.



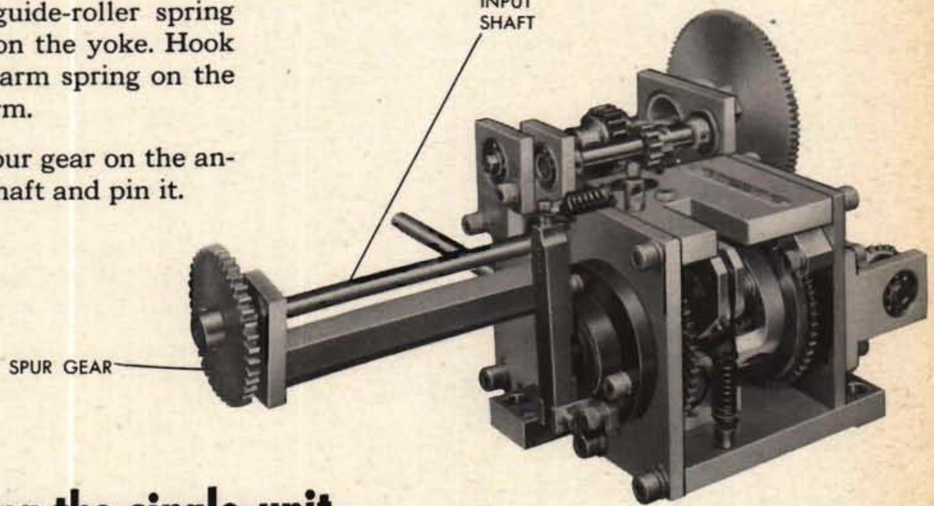
20 Slide the front plate on the shafts. Carefully fit the dowels into the holes, and mesh the marked teeth of the top angle gear and the gear on the angular input shaft.

21 Lubricate the ball with approved lubricant. Hold up the pivoted guide roller, and insert the ball.



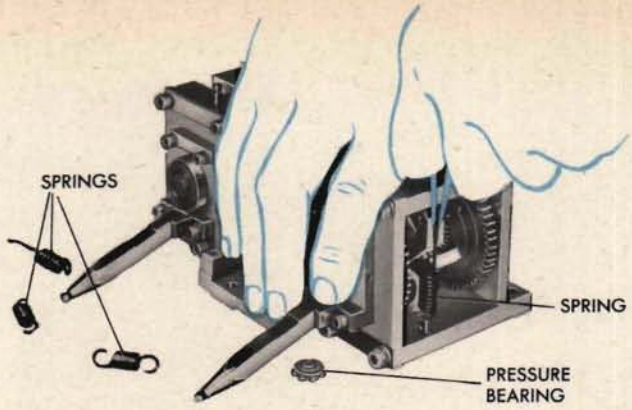
22 Using several loops of strong twine around the end, stretch the pivoted-guide-roller spring and hook it on the yoke. Hook the pressure-arm spring on the end of the arm.

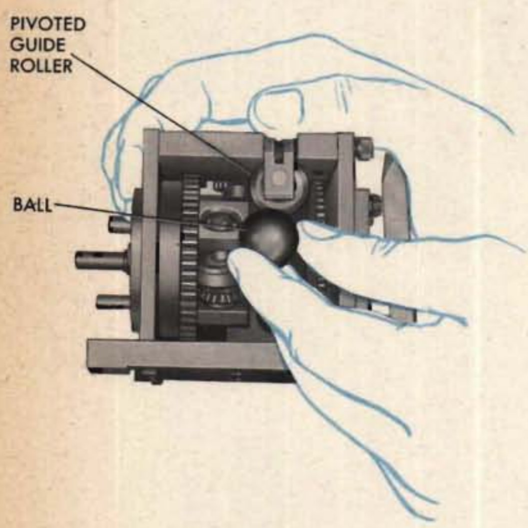
23 Mount the spur gear on the angular input shaft and pin it.



Bench checking the single-unit

1. Check the unit assembly against the assembly drawings.
2. The upper guide roller axis should be parallel to the input roller axis.
3. The gear meshes should be free, with minimum lost motion, and the shafts should have minimum end shake.
4. Turning the linear input should turn all rollers when the input roller axis is parallel to the pivoted-guide-roller axis.





Disassembling the double-unit

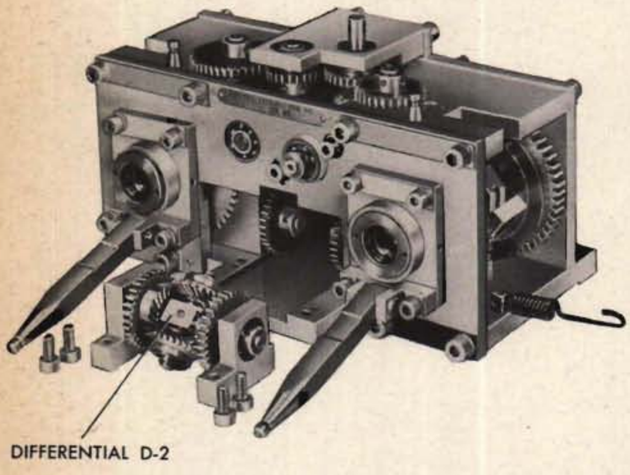
The double-unit component integrator described and illustrated in this chapter is from the Computer Mark 1. Be sure to tag all spacers as they are disassembled.

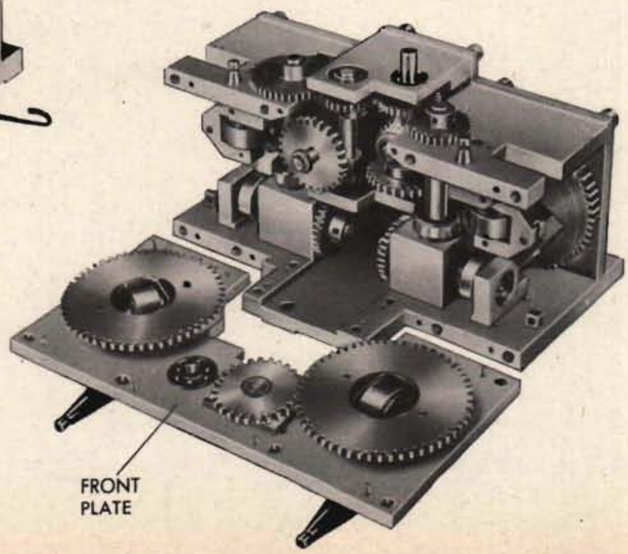
1 Use several loops of strong twine to unhook all four springs. Lift out the pressure bearings.

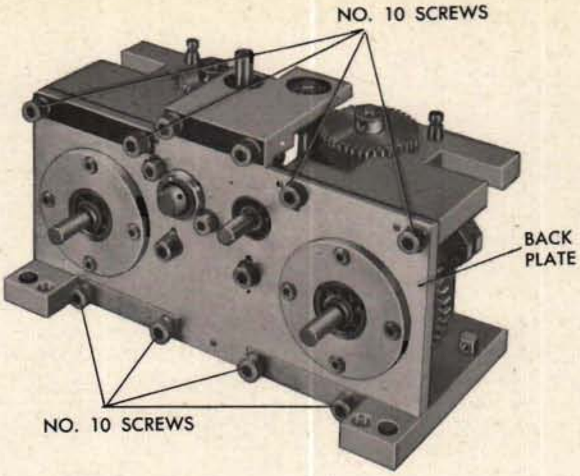
2 Hold up the pivoted guide roller of each unit and remove each ball.

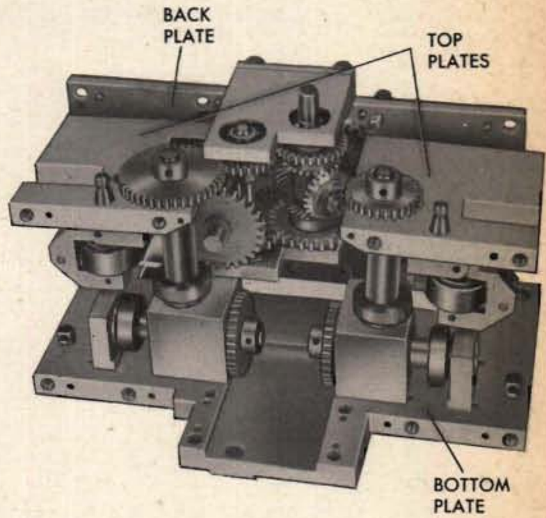
3 Remove differential D-2 after removing the four screws on the under side of the lower plate.

4 Remove the eight No. 10 screws and pull off the front plate. Tag the spacers.







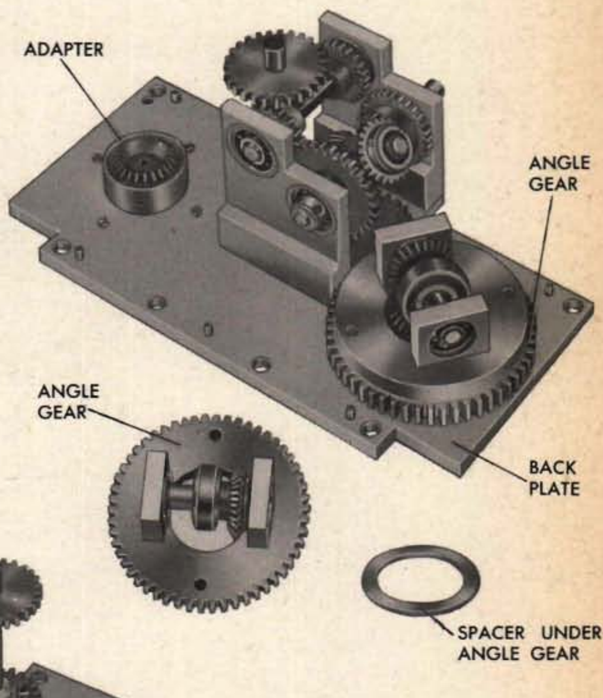


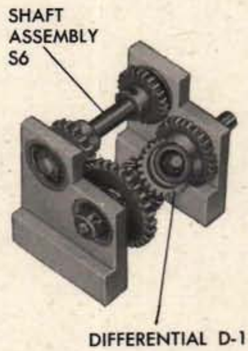
5 Remove the eight No. 10 screws in the back plate.

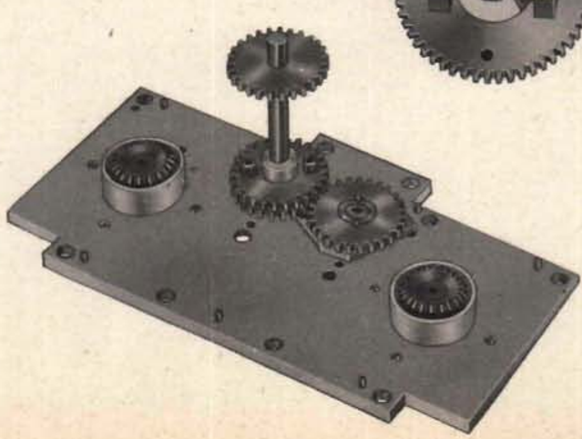
6 Separate the top plates and the bottom plate simultaneously from the back plate to avoid bending the dowels.

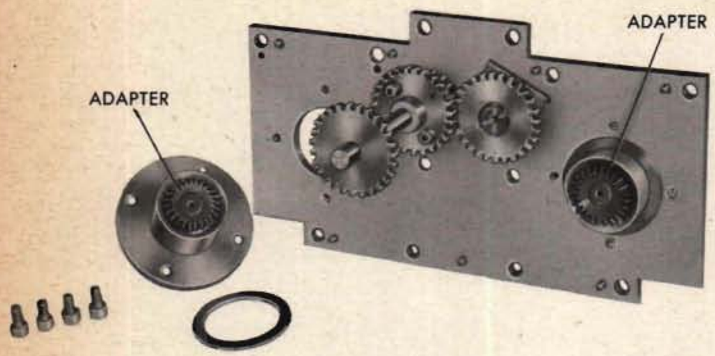
7 Pull the angle gears off their adapters on the back plate. Tag the big spacers under the angle gears.

8 Remove four No. 8 screws and lift off the hanger assembly in which differential D-1 and shaft assembly S6 are mounted.

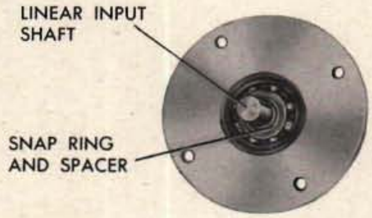






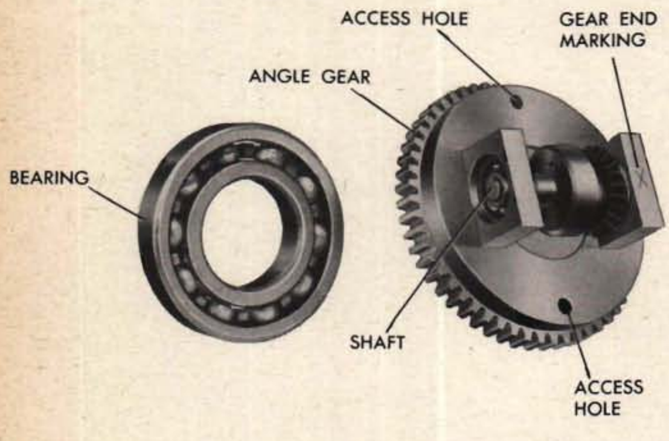


9 Remove the eight No. 6 screws and lift out the two adapters which support the linear input shafts.



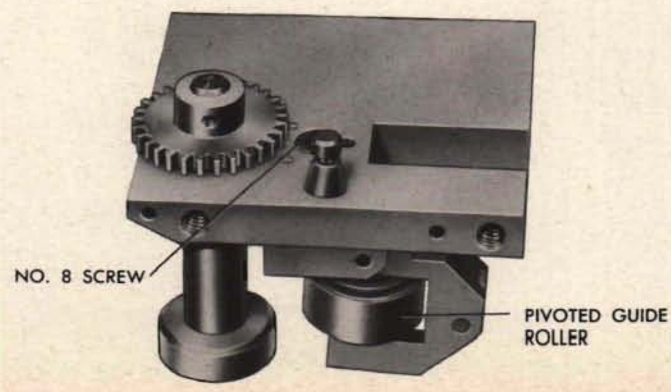
10 Remove the linear input shafts from their adapters after pushing off their snap rings.

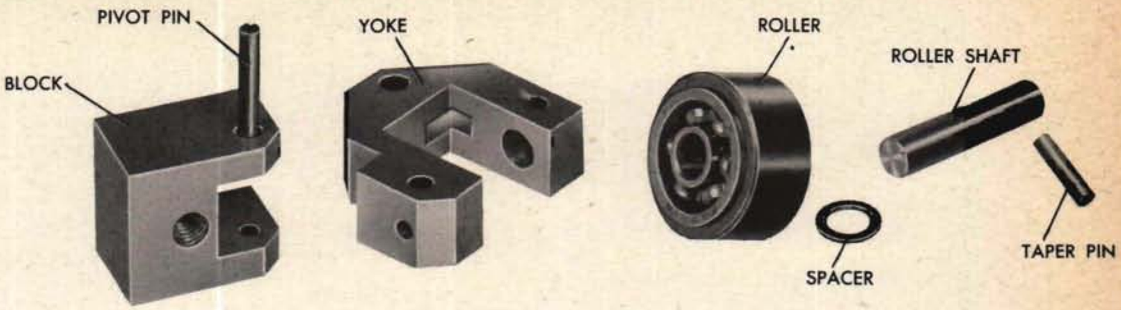
11 Remove the bearing from each angle gear by carefully tapping the outer race with a punch through the access holes in the gear.



12 Before removing the input roller, mark the hanger near the gear end of the shaft. Then drive out the taper pin, and push out the shaft.

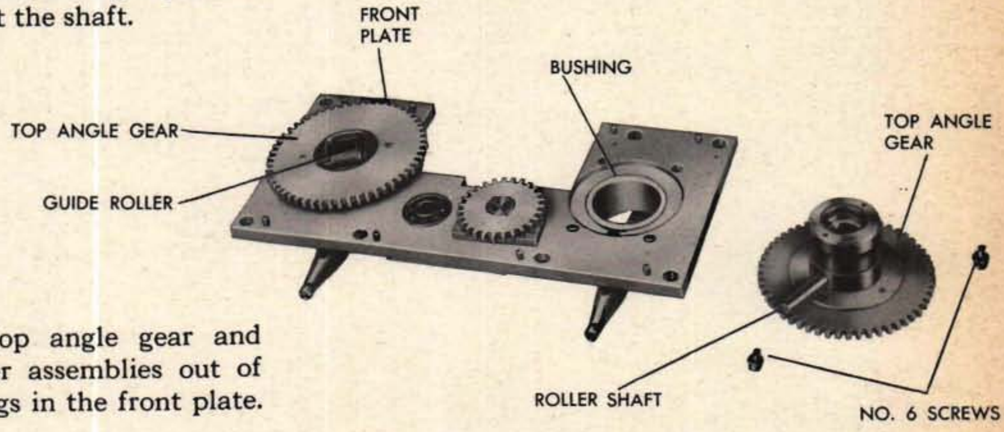
13 To remove the pivoted guide roller from the top plate, remove the No. 8 screw and pull the block off the dowels.





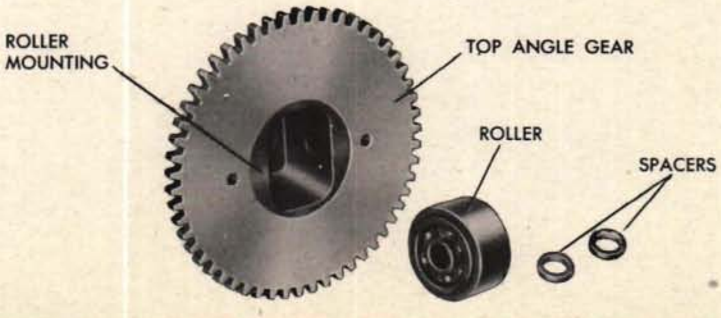
14 Separate the yoke and block by driving out the pivot pin.

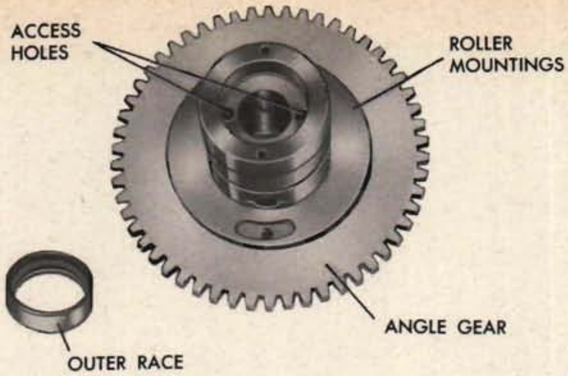
15 Remove the roller from the yoke by driving out the taper pin and pushing out the shaft.

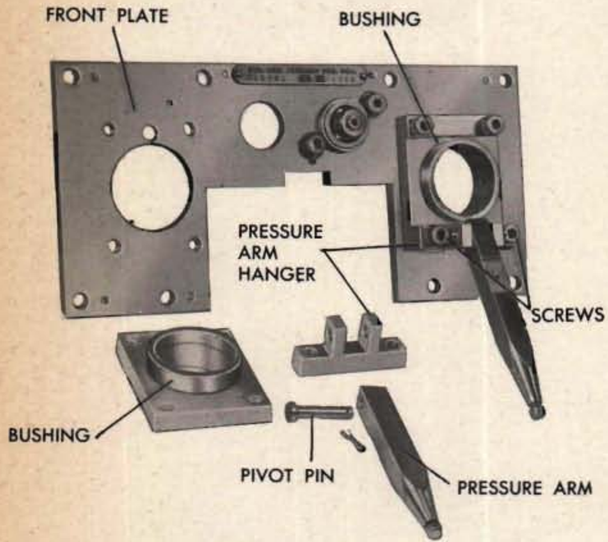


16 Pull the top angle gear and guide roller assemblies out of the bushings in the front plate.

17 To remove the guide roller from its mounting, take out the two No. 6 screws and drive out the shaft.







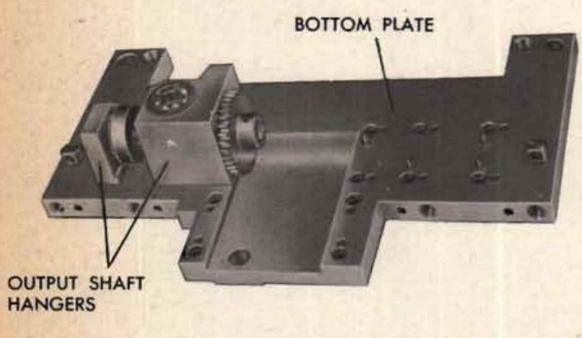
18 Remove the outer race of the pressure bearing by carefully pushing through the access holes in the roller mounting.

19 Take out the four No. 8 screws holding the pressure-arm hangers to the front plate, remove the cotter pins, and push out the pivot pins to separate the pressure arms from the hangers.

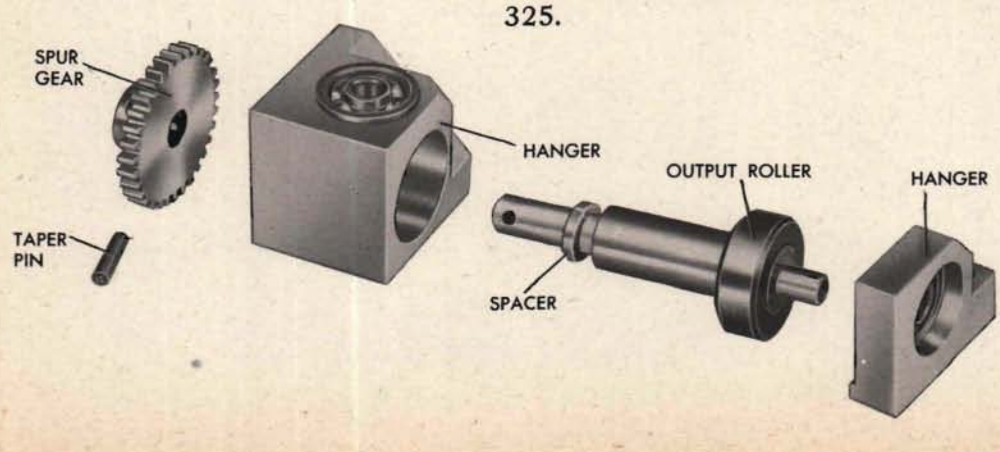
20 Take out the four remaining screws and remove the bushings.

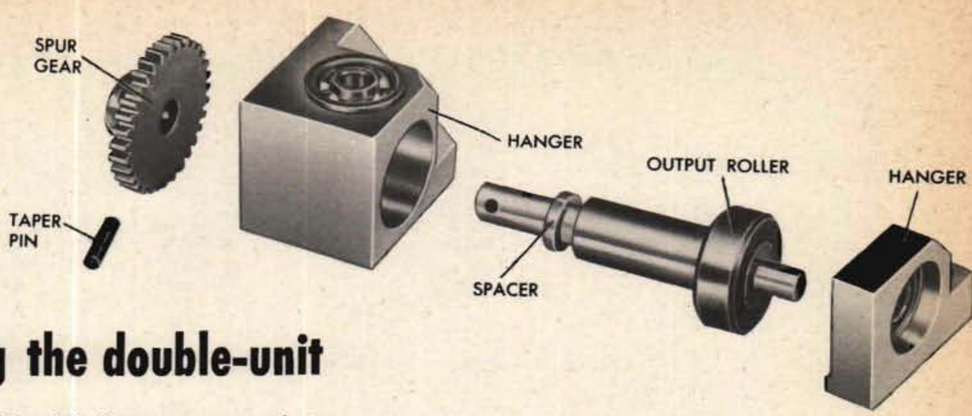
21 To remove the output shaft assemblies, take the screws out of the bottom of the lower plate and carefully lift the hangers off their dowels.

22 Drive the taper pins out of the spur gears and separate the roller assemblies.



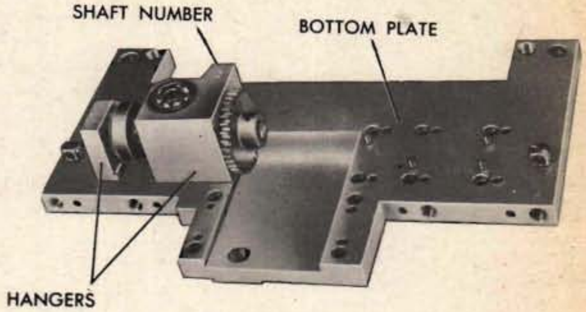
TO REPAIR THE DOUBLE-UNIT, CONSULT INSTRUCTIONS ON PAGES 324-325.





Reassembling the double-unit

In order to reassemble this integrator so that the parts will fit together nicely and the settings between the units will be accurate, remount the parts in their original positions. The important parts are marked or numbered for ease in identification. The spacers should have been tagged at disassembly.



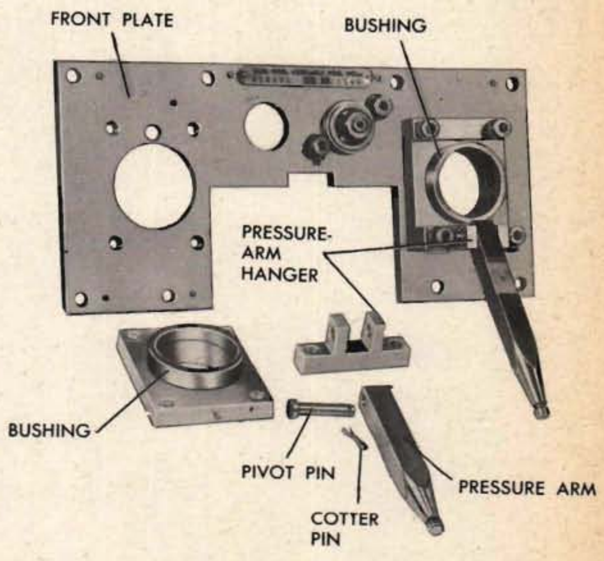
1 Mount each output roller shaft in its hangers and pin the spur gears to the shafts.

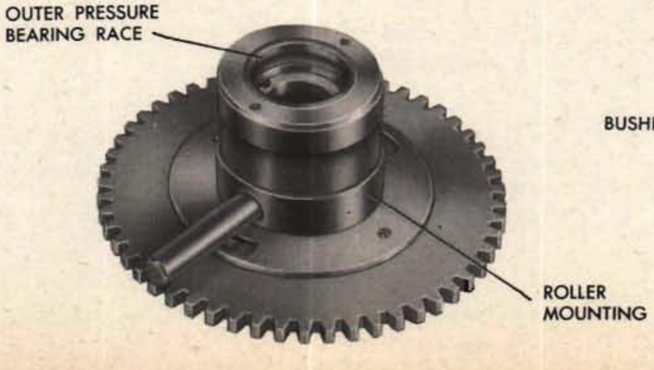
2 Mount the hangers on the bottom plate according to the shaft numbers.

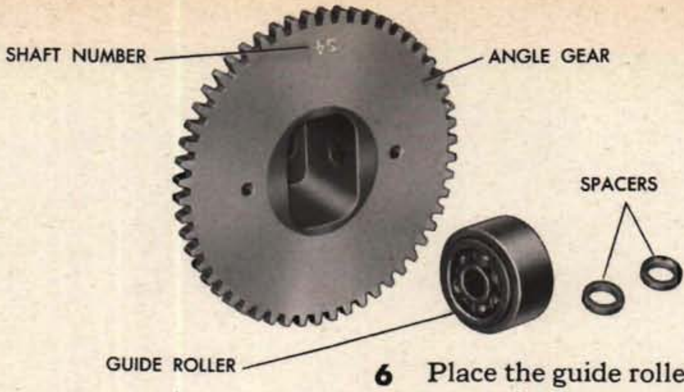
3 Hold each pressure arm in position in its hanger and slip the pivot pins in place. Replace the cotter pins.

4 Mount the bushings and pressure-arm hangers on the front plate as shown.

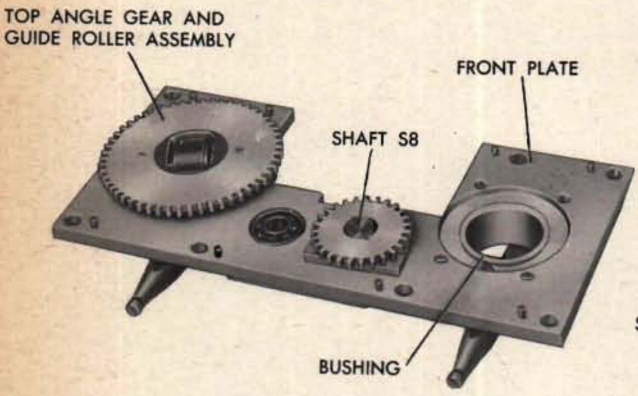
5 Replace the outer race of the pressure bearing in the roller mounting.

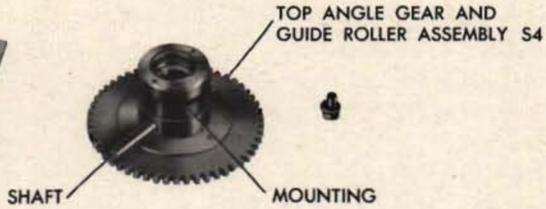




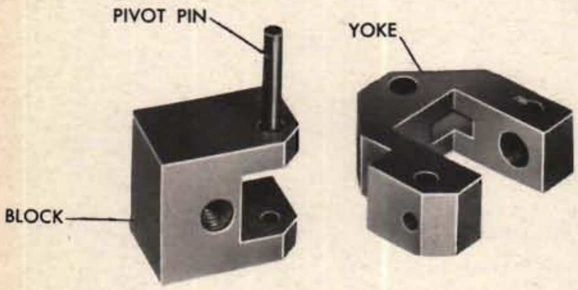


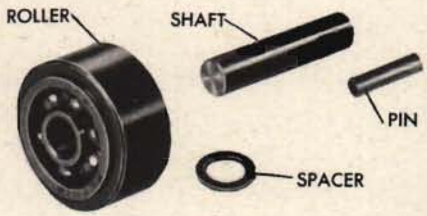
6 Place the guide roller and spacers in the mounting, push the shaft into position, and stake both ends of the shaft. Replace the two screws.





7 Slide the top angle gear and guide roller assemblies into the bushings in the front plate. Mesh the marked teeth of angle gear S4 with corresponding mark on the gear pinned to shaft S8. (There are two marks on this gear, one for the angle gear, and one for the gear on the angular input shaft.)

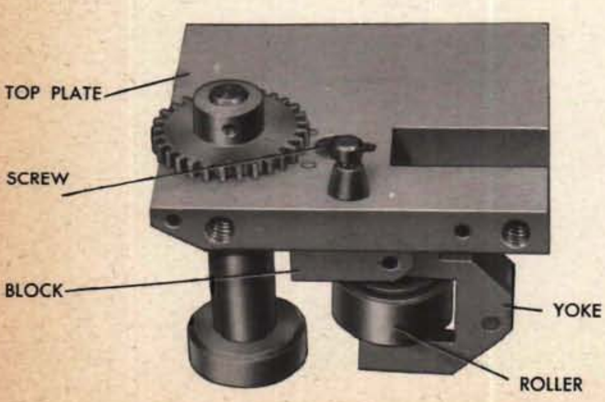


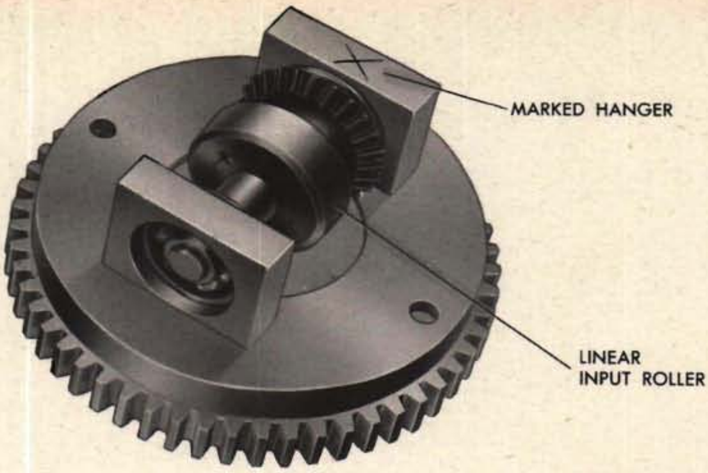


8 Mount the roller and spacer in the yoke and push the shaft into position. Pin and stake it.

9 Mount each yoke in its block. Push the pivot pins into place, and stake them at both ends.

10 Push the blocks onto the dowels in the top plates and fasten with screws from the top of the plates.

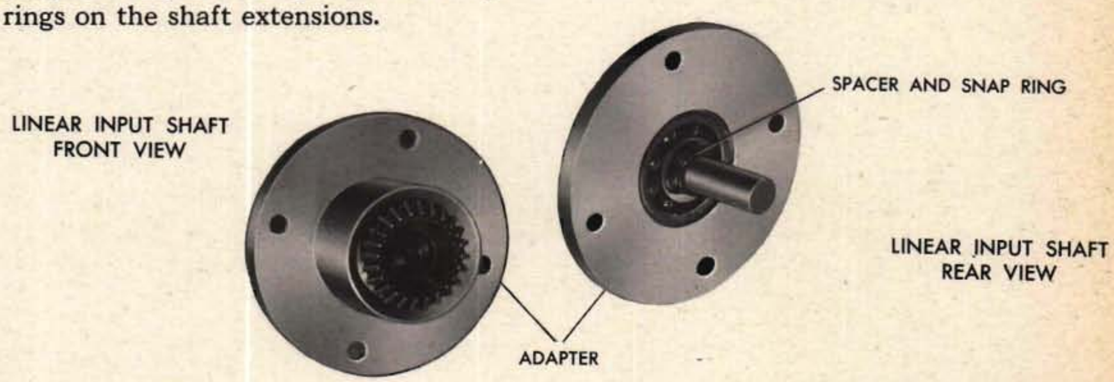




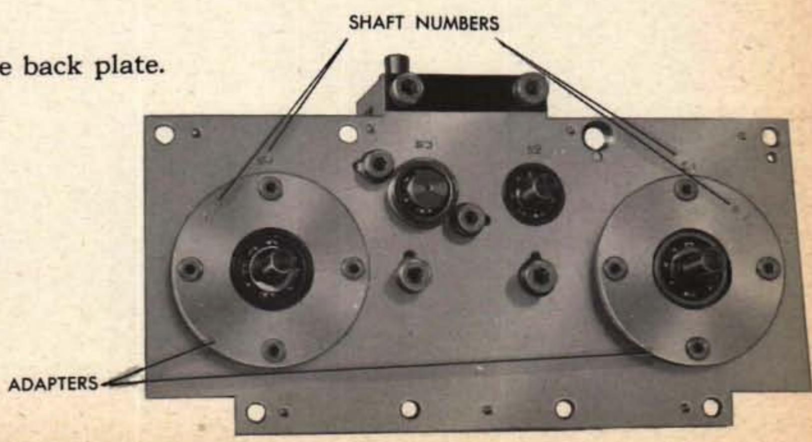
11 Mount the linear input rollers in the angle gears so that the roller gears are toward the marked hangers. Repin the gear to the shaft.

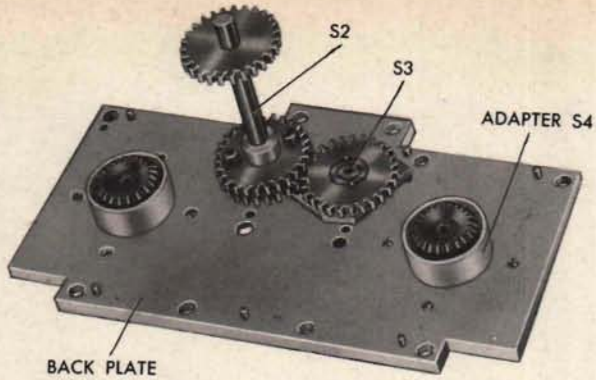
12 Insert the large bearings in the angle gears.

13 Slide the linear input shafts into the adapters. Replace the spacers and snap rings on the shaft extensions.



14 Mount the adapters in the back plate.

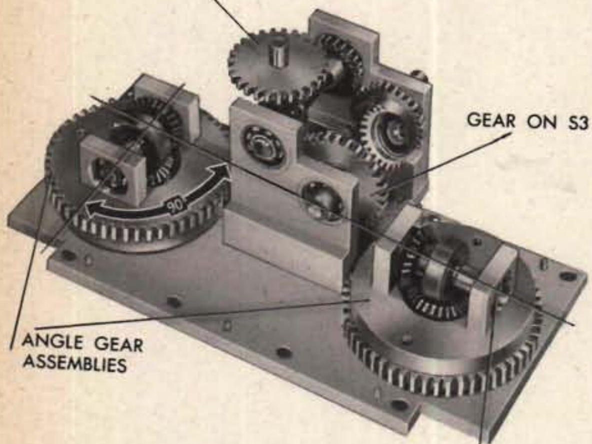




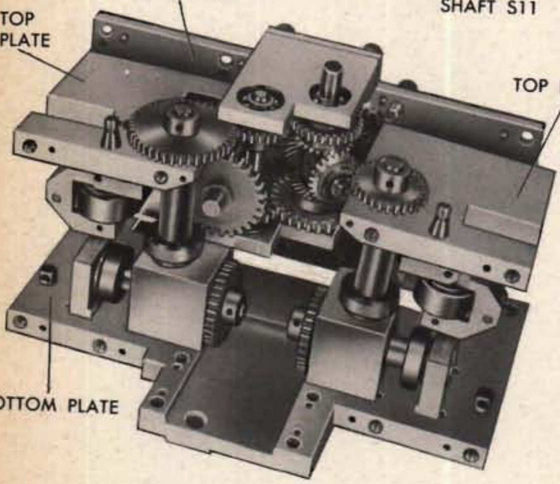
15 Mount the hanger assembly containing differential D-1 and shaft assembly S6 on the back plate.

16 Replace each large spacer on its adapter. Mount the angle gear with input roller shaft S11 on adapter S4. Mount the other angle gear so that the input roller axes are at right angles to each other, with the bevel-gear ends in the relative positions shown.

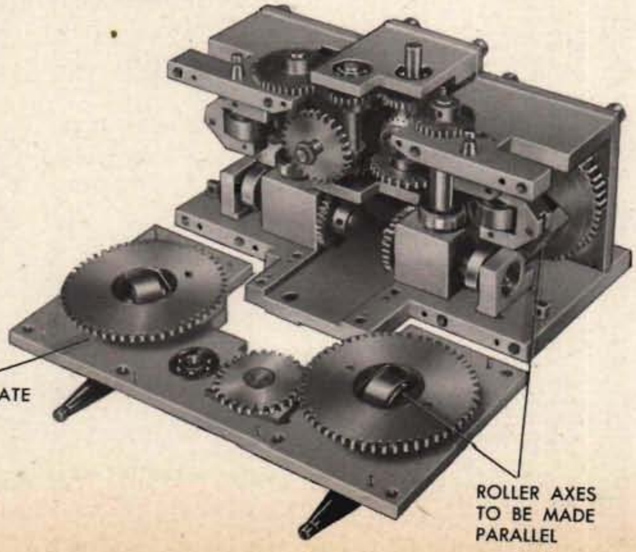
Mounting the angle gears with their marked teeth meshing with the marked teeth of the gears on shafts S2 and S3 will accomplish this, provided the relative position of the gears which are doweled together has not been altered.



17 Simultaneously push the top and bottom plates onto the dowels in the back plate.



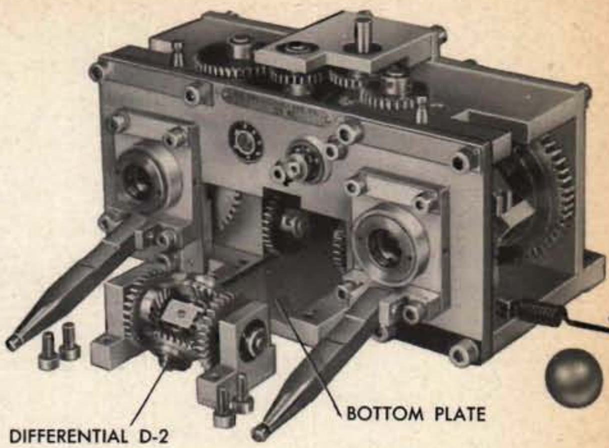
18 Mount the front plate, making the gears mesh so that the axes of the guide rollers in the top angle gears are parallel to the axes of the corresponding input rollers.



19 Mount differential D-2 on the bottom plate and fasten the four screws under the plate.

20 Hold up the pivoted guide rollers, and replace the balls.

21 Hook the two pivoted-guide-roller springs, insert the pressure bearings and then hook the lever-arm springs.



Bench checking the double-unit

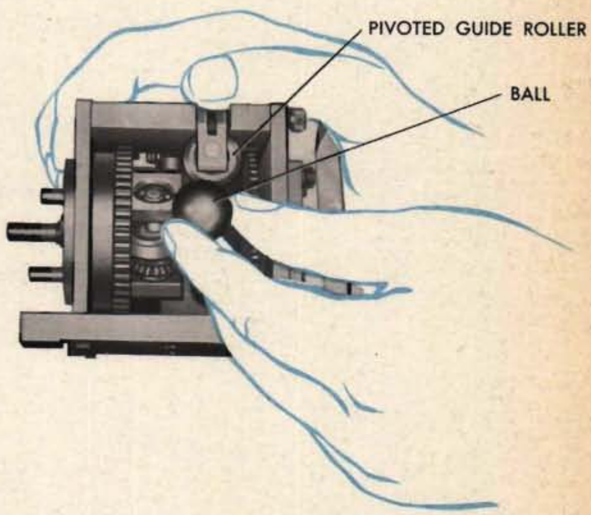
1 Check the unit against the assembly drawings.

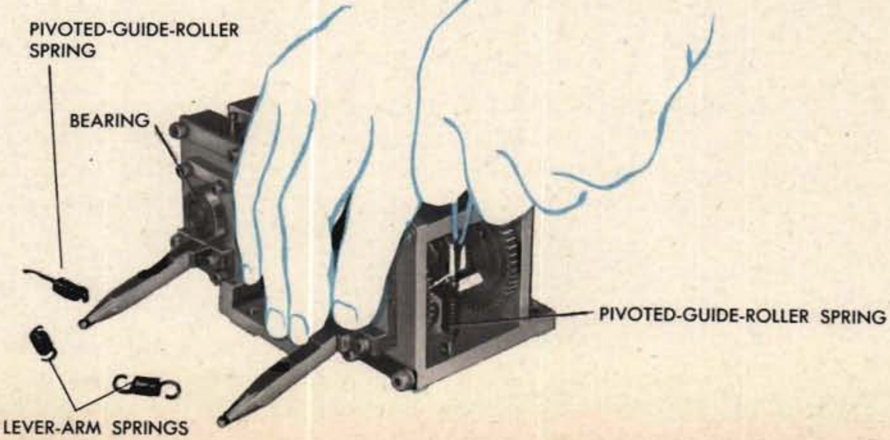
2 Shafts and gears must turn freely, with a minimum of end play and lost motion. (Component integrator shafts normally turn somewhat stiffly because the balls and rollers are under spring pressure.)

3 Turn the angle gear of one integrator to a position where turning its linear input shaft causes only one of its output shafts to turn. Now if the axes of the input roller shafts of both integrators are at right angles to each other, only one output of the second integrator will turn when the linear input shaft of the second integrator is turned.

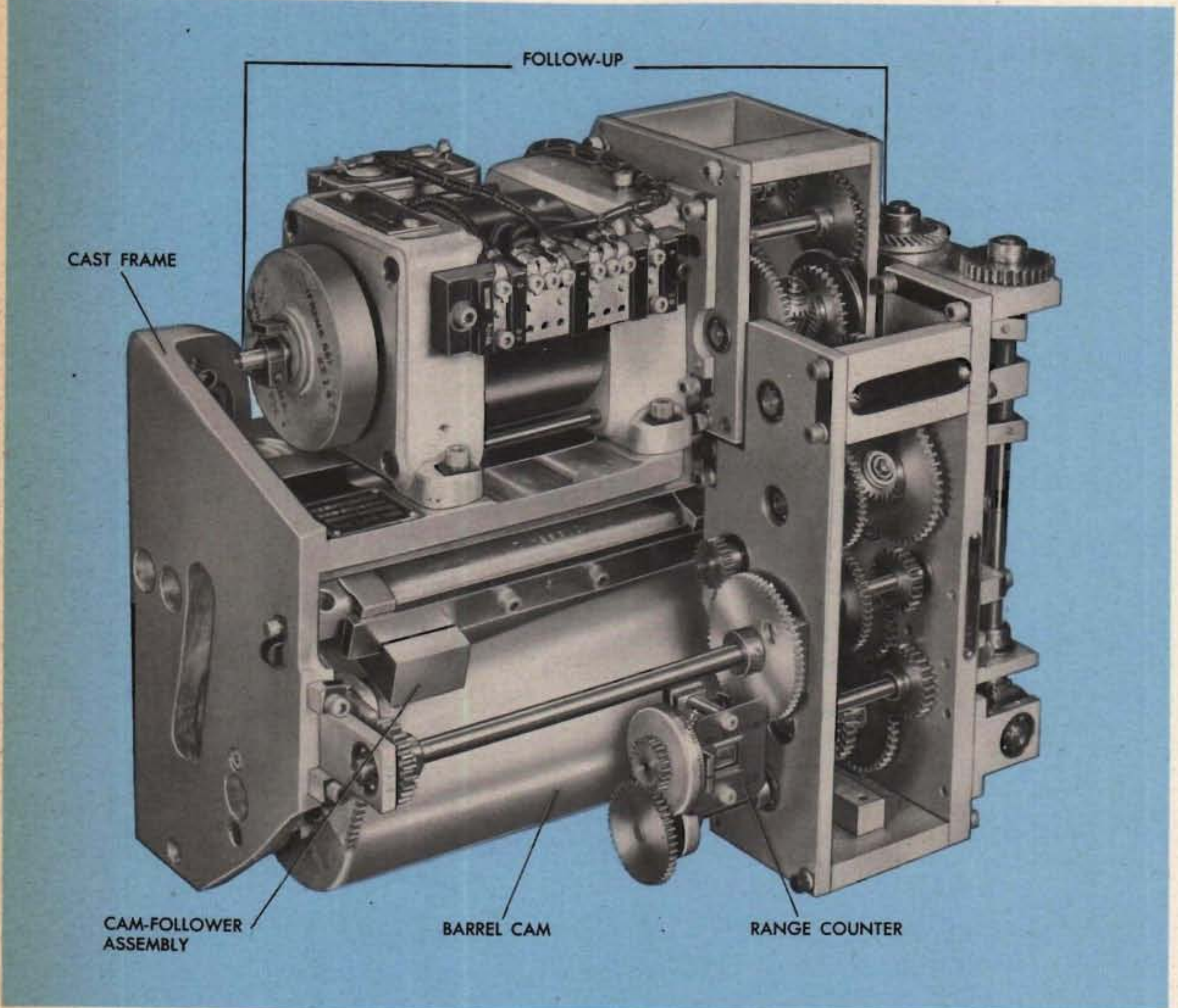
4 Turn the angle gear until the axis of one input roller is parallel to the pivoted-guide-roller axis. Now, turning both linear input shafts should turn all outputs.

5 Check that the angle gear assemblies are in the correct relationship to each other. (See step 16 in the reassembly.)



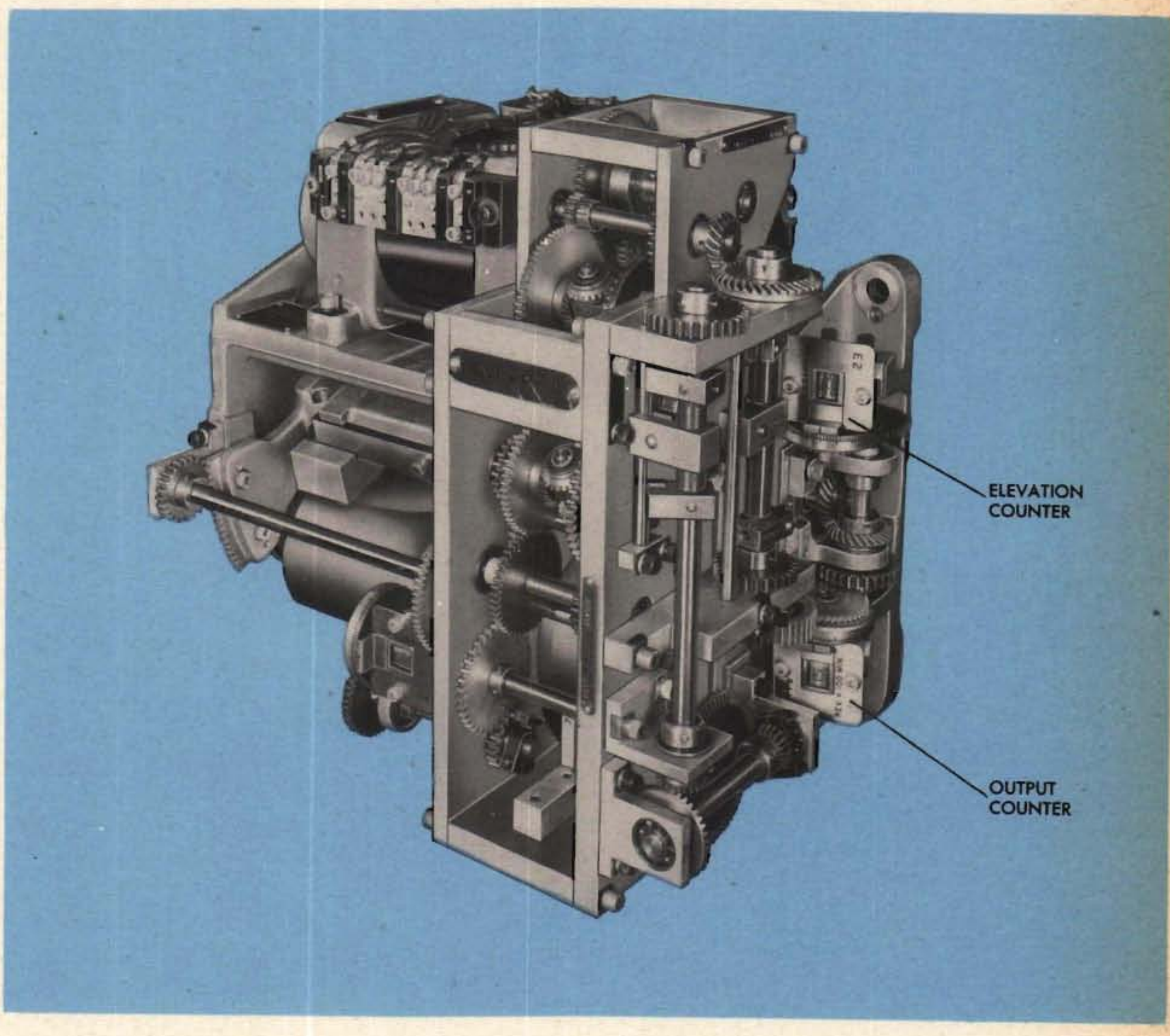


THE BALLISTIC COMPUTER



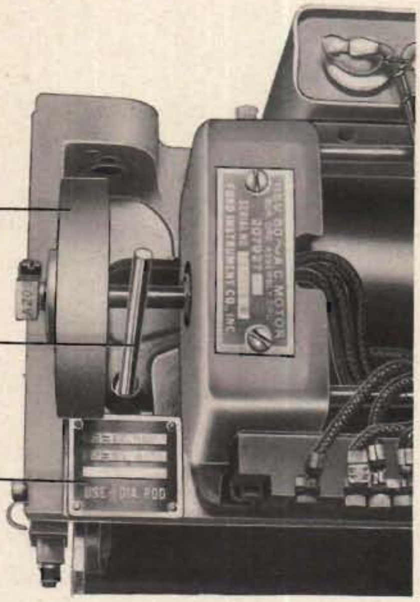
A ballistic computer is a small computing instrument in itself. Either on the bench or in the main instrument, its outputs very closely approximate the values provided in ballistic data tables for any given advance range, *R2*, and predicted target elevation, *E2*.

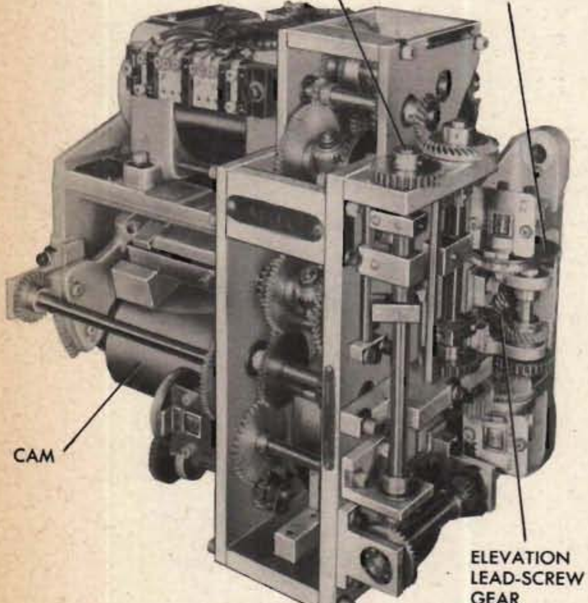
The functional portions of a ballistic computer are: a barrel cam and follower assembly, a follow-up, input and output shaft lines, and a cast frame on which all the parts are mounted. Three counters which register the input and output quantities are mounted on the ballistic computer making it a completely self-contained computing unit.



There are two types of ballistic computer: one with a magnetic drag follow-up, used in Computer Mark 1, and another with an oscillating follow-up, used in Range Keeper Mark 10. All Mark 10 fuze computers and all Mark 1 fuze computers of Ser. Nos. 781 and higher are regenerative. That is, the output, fuze, positions the cam.

This chapter is concerned specifically with the Mark 1 ballistic computer. In general, however, the symptoms, causes, and repairs discussed here are common to both types of unit. If a ballistic computer must be removed from the instrument for repair, consult the instrument OP for instructions.





Typical symptoms

A test analysis and unit check test may have shown that the output values given by a ballistic computer do not agree with those on the ballistic test sheet or the instrument A-test sheet. Or a bench test of the unit may have indicated the same trouble: incorrect output. In either case, look for one or more of the following typical symptoms:

Electrical trouble

The follow-up motor has little or no torque, runs in only one direction, or runs away.

Mechanical trouble

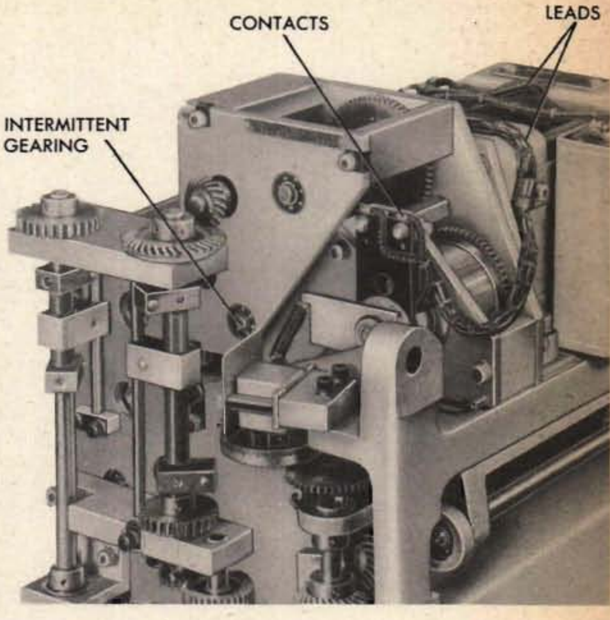
SLIPPING: When a 3/16-inch setting rod is inserted through the follower arm and cam, the range and elevation input counters are not at the values indicated on the legend plate. When the cam is held by one hand, the range input can be turned with the other hand; or when the elevation lead screw is turned against one of its limits, the gear which meshes with the elevation counter can be further turned, while the lead screw does not rotate.

EXCESSIVE LOST MOTION: When one end of a shaft line is held, too much over-all play can be felt at the other end; or excessive lost motion due to wear can be felt between the traveling nut and lead screw.

JAMMING: The input or output gearing or the follow-up strongly resists moving.

STICKING: The input gearing moves sluggishly or resists moving past certain points. Or the output gearing may turn roughly and erratically when the power is ON, and resist moving or move sluggishly when the power is OFF.

Locating the cause

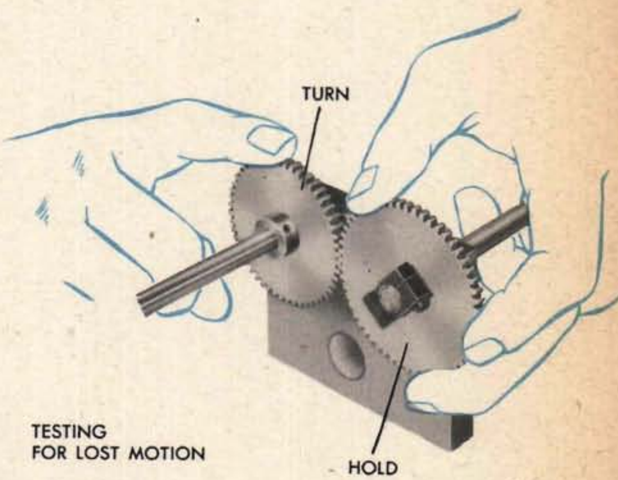


Electrical trouble

Weak servo-motor torque is usually caused by a faulty capacitor or defective wiring. No torque at all and one-way response both indicate an open lead or dirty or damaged contacts. Runaway response may be caused by reversed leads, contacts jammed together, or improperly assembled intermittent gearing.

It is not usually necessary to disassemble the unit in order to clean or replace contacts, repair the wiring, or replace a capacitor. Repairing or adjusting the follow-up gearing requires partial disassembly.

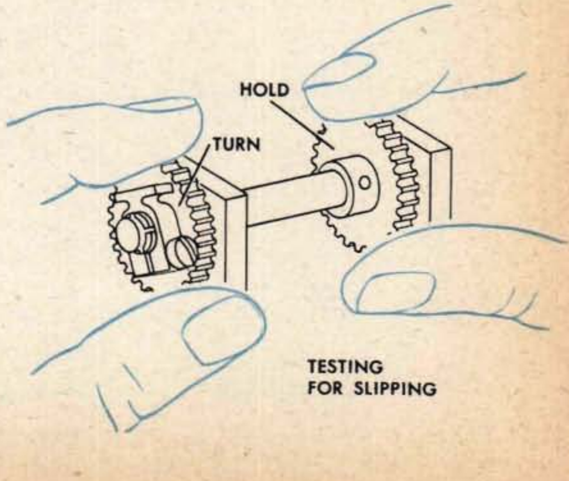
For specific and detailed discussions of the electrical parts of the ballistic computer, see the chapters on *The Servo Motor,* page 426; on *The Follow-up,* page 402; and on *Wiring,* page 380.



TESTING
FOR LOST MOTION

Mechanical trouble

If the electrical parts of the unit are operating normally and the cam is properly aligned, it is necessary to check the four shaft lines within the unit for jamming, sticking, excessive lost motion, or slipping. These four lines are the *elevation* and *range input lines* and the *cam* and *motor output lines.*



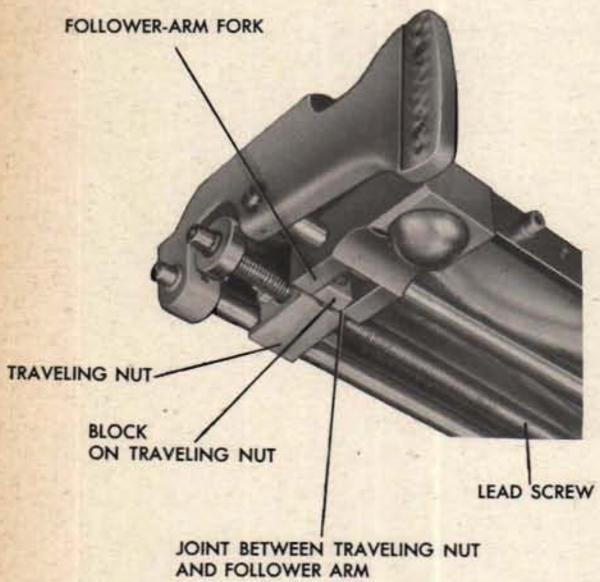
TESTING
FOR SLIPPING

It is assumed that the trouble shooter is already familiar with the chapters in this OP on *Shaft Lines* and *Basic Repair Operations.*

Isolating the four shaft lines

In order to check the four shaft lines within the unit, each line must be mechanically isolated from the others.

The following explanation of the method of isolating the lines for checking is presented in terms of jamming or sticking. This method can also be applied to locating excessive lost motion or slipping. Refer to SLIPPING and EXCESSIVE LOST MOTION, page 344.

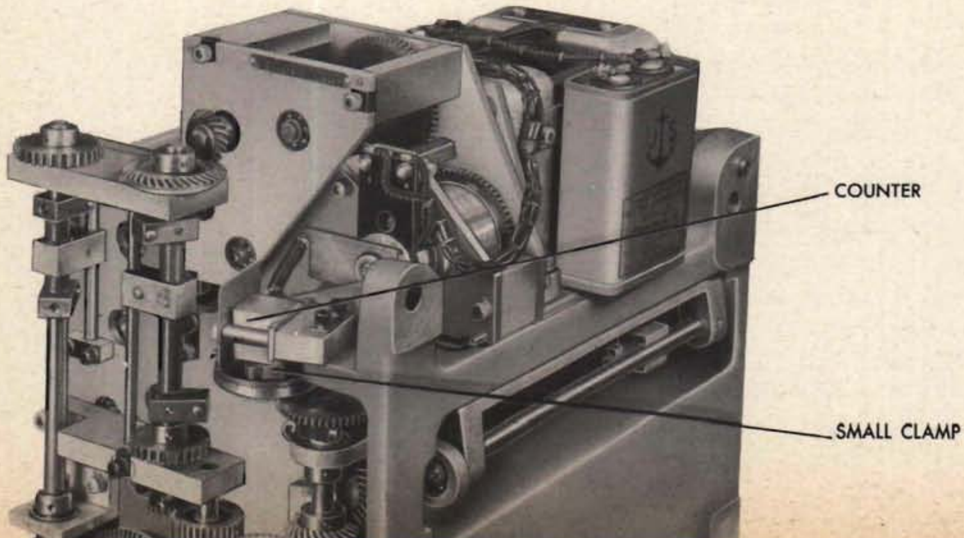


The unit should be disassembled and parts replaced only if wear has caused excessive lost motion between the lead screw and the traveling nut, in the joint between the block on the traveling nut and the follower-arm fork, or in gear meshes between plate-mounted shaft assemblies.

In general, the best procedure is to turn each line separately by hand when the power is OFF, in order to locate the particular shaft line which is not operating normally.

Always eliminate the possibility that a counter is jamming or sticking before checking the shaft line further. A counter may be loosened or even removed for repair without disturbing the adjustments, provided the shaft line is still connected to the main counter in the instrument. If the input shaft of a jammed counter has sheared off or is slipping through the small clamp which holds it, the whole line may stick.

Counters are discussed in a separate chapter, page 148.



To isolate the elevation input line, first lift the follower frame so that the follower and the cam are disengaged. Then turn the line by rotating the gear next to the elevation counter. If the line jams or sticks, refer to the section on checking the elevation input line, pages 348-349. If it operates normally, isolate the range input and cam output lines.

To isolate the range input and cam output lines, first lift the follower frame to disengage the follower from the cam. Then turn the range input gear. This will normally turn the range input line, the cam, and the follow-up input gearing.

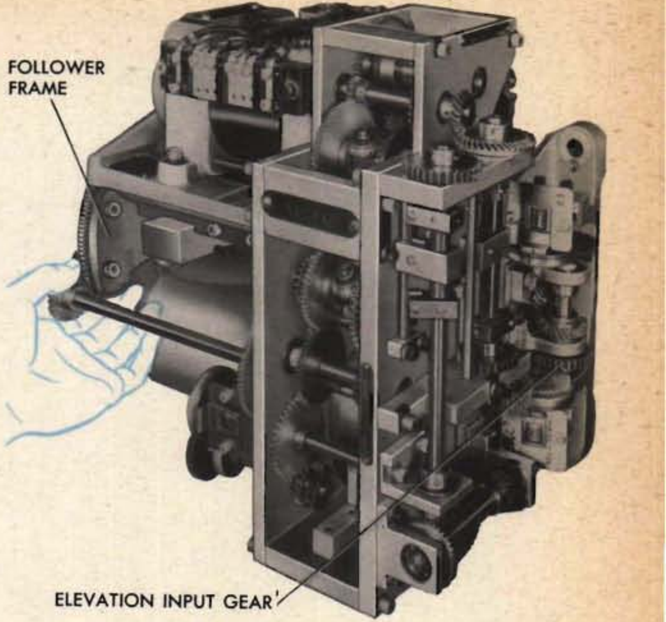
If they jam or stick, hold the range input gear and let the follower frame go down slowly by its own weight. If it goes down easily without jamming or sticking, the cause of the trouble is probably in the range input line. Refer to the section in this chapter on checking the range input line, page 350.

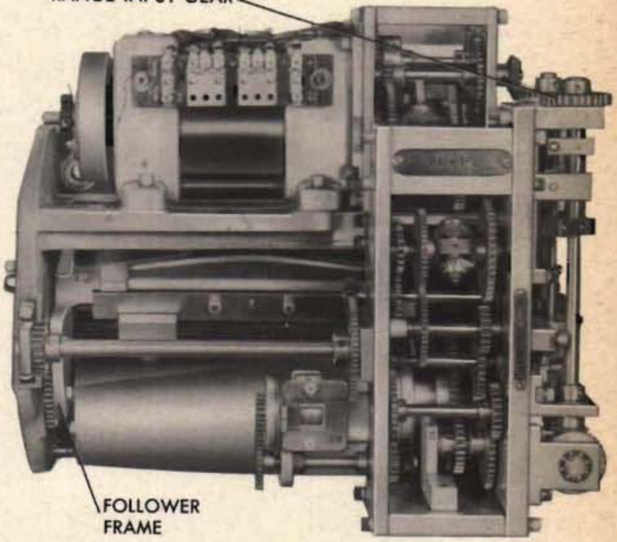
If the follower frame does not go down normally, the cause of the trouble is probably in the cam output line. Refer to the section on checking this line, page 350.

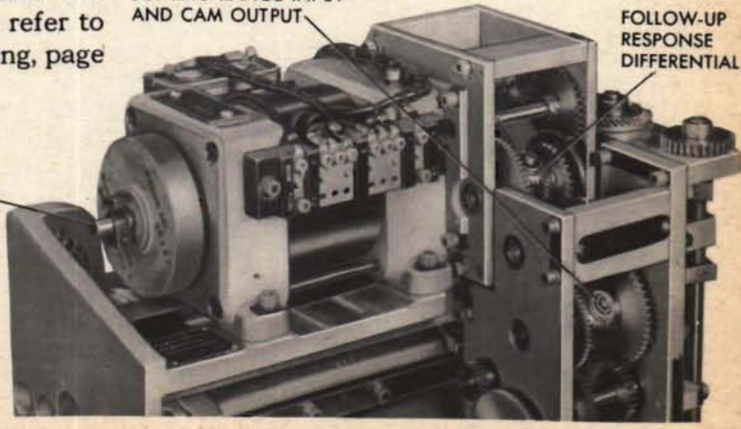
If both lines jam or stick, the cause may be in one of the differentials or in the follow-up input gearing. Refer to the chapter on the bevel gear differential, page 174, or the chapter on the follow-up, page 402.

If both lines operate normally, isolate the motor output gearing.

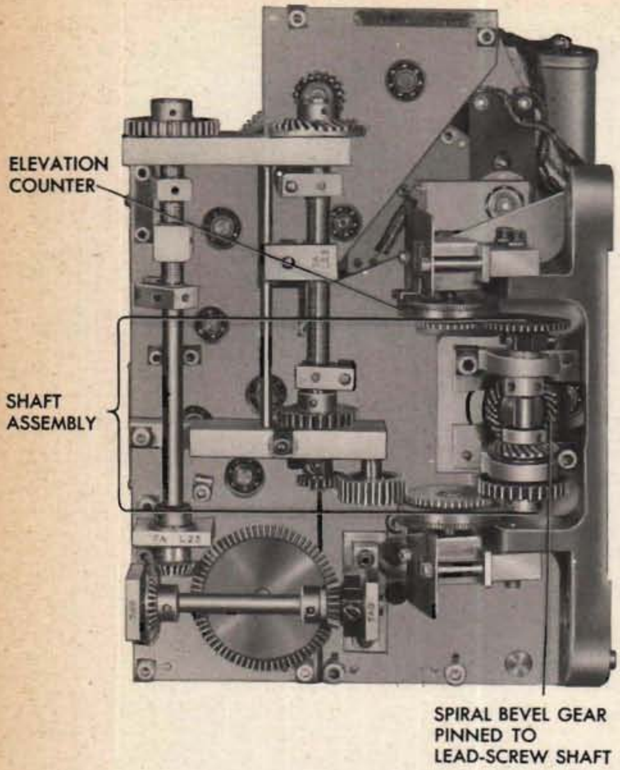
To isolate the motor output gearing, turn the servo-motor shaft extension. This will normally turn the motor output line and the response gearing. If it jams or sticks, refer to the section on the motor output gearing, page 351.







Elevation input line



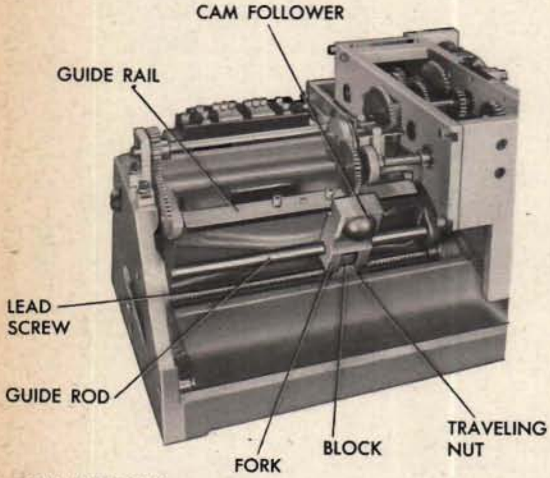
The elevation input line consists of a counter, a shaft assembly, a lead screw and traveling nut assembly, and a follower arm which is joined to the nut by means of a fork and block. The follower arm slides on a guide rod and against a guide rail. The steel-ball cam follower is mounted in the arm and slides on the cam.

To isolate this line, first lift the rocker arm so that the follower and the cam are disengaged. Then turn the line by rotating the gear next to the elevation counter.

If the line jams or sticks, the cause may be: dirty or damaged bearings or gears, or a tight gear mesh; a bent, dirty, damaged, or dry lead screw, traveling nut, or guide rod; a dirty, bent, or damaged pivot rod; or interference of parts, such as a counter drum rubbing on an adjacent part of the unit.

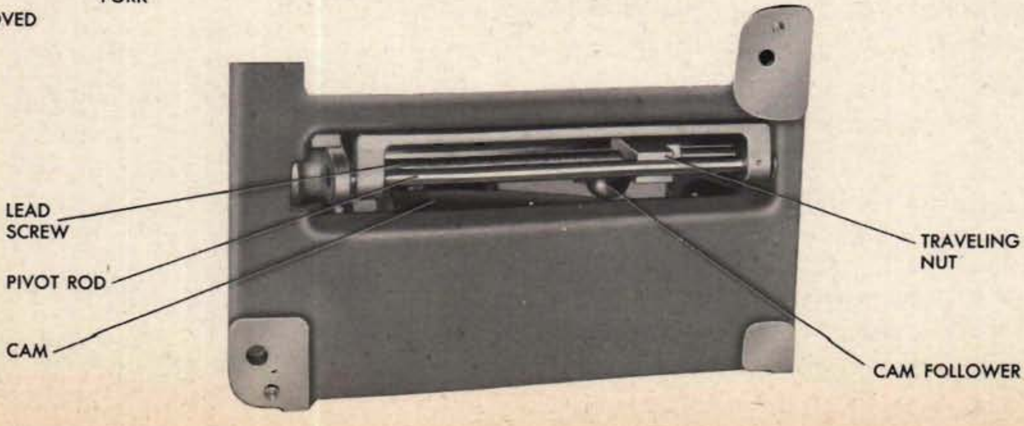
A tight gear mesh feels heavy, or like a ratchet device when the line is turned by hand. Dirty or damaged gear teeth or bearings can usually be detected by a feeling of intermittent binding, or roughness, when the line is turned.

Dirty or dry parts can usually be cleaned and lubricated without disassembly of the unit, and minor nicks in threads or gear teeth repaired in place. But a damaged lead screw or traveling nut usually must be removed from the unit for repair or replacement.



CAM REMOVED

The elevation lead screw of a Mark 1 ballistic computer is designed to function as a limit stop, and therefore the traveling nut is not likely to jam against its limit.

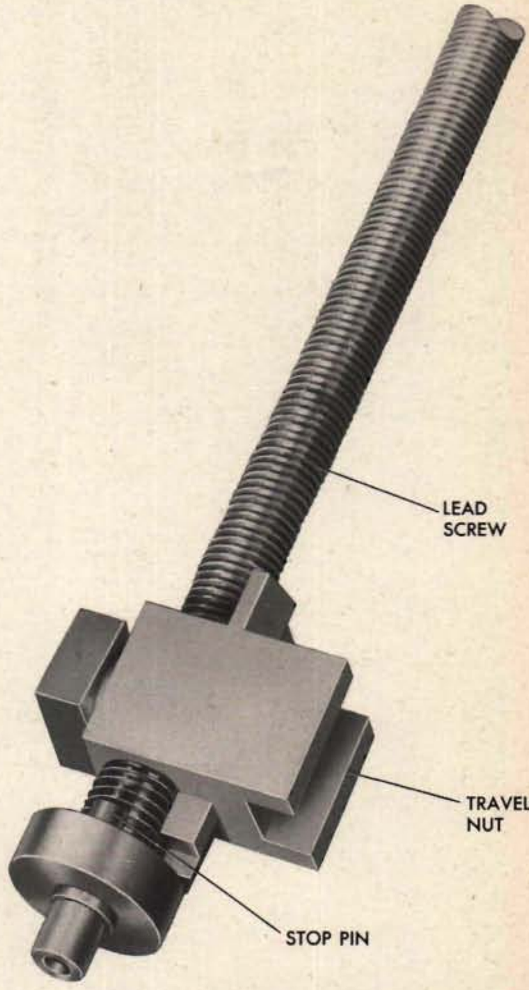


If the nut should jam at either limit of its travel, it can probably be backed out of its jammed position by hand and may not require any repair.

In the Mark 10 unit, however, the elevation lead screw does not function as a limit stop. It can be out of adjustment with the elevation limit stop so that the follower jams at either end of its travel. Consult the instrument OD for instructions on adjusting the limit stop. If the limit stop cannot be adjusted properly or needs repair, refer to page 106.

A bent lead screw usually turns stiffly at one point during each revolution in the proximity of the bend. The screw ordinarily cannot be straightened by hand, hence should be replaced.

A bent guide rod will cause increasing or decreasing stiffness of movement throughout the travel of the nut. A bent guide rod can be straightened in the same way as a bent shaft. See pages 68 and 69.

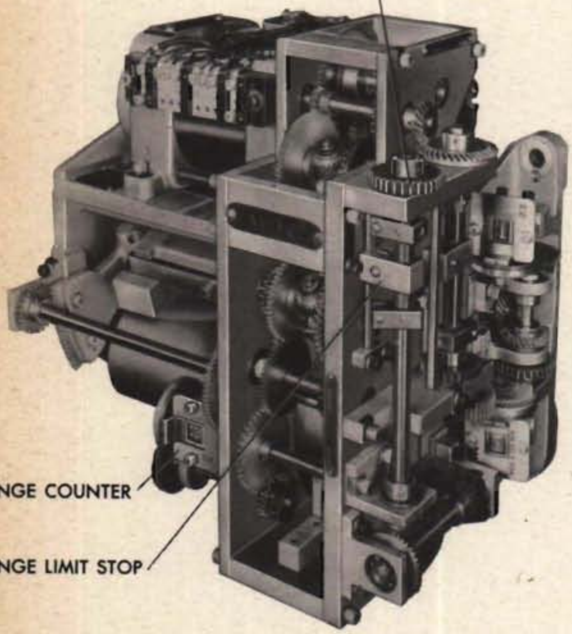


A dirty or damaged lead-screw thread, guide rod, or rail may cause a feeling of stiffness only once in the entire travel of the nut. Damaged threads in the traveling nut or a dry lead screw or rod may cause a constant feeling of stiffness throughout the normal travel.

The lead screw is steel, and the nut aluminum. Do not use the nut to run in a damaged screw thread, because it will cut away the aluminum. Do not use a tap for the nut or a die for the screw because both are double-threaded. Small nicks on the threads of the lead screw may be removed, or smoothed out with a fine jeweler's file. Excessive lost motion between the screw and nut requires replacement of the nut at least.

A damaged guide rail must be replaced because it must have an absolutely flat surface. Never try to smooth out a nick in a guide rail.

In general, the amount of disassembly required will be determined by the particular casualty which is found. Carefully examine the faulty part, the connected and adjacent mechanisms, and follow the appropriate steps of the disassembly procedure.



Range input line

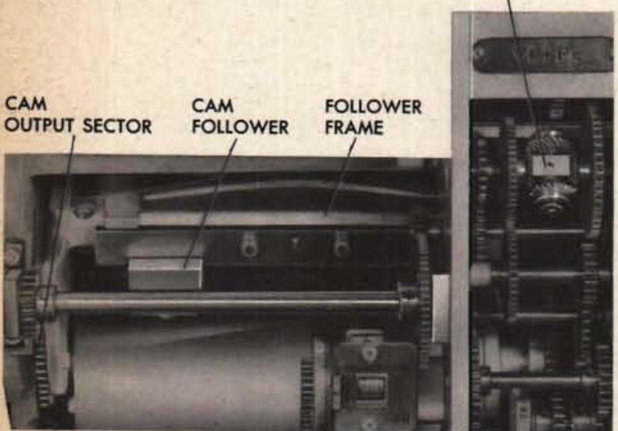
The range input line consists of a counter, a limit stop, and the gearing to the cam and the follow-up control. The range line turns the cam and joins the cam output line to turn the follow-up control gearing. When an output line is turned with the servo power OFF, do not mistake the normal resistance of the intermittent gearing for sticking. To prevent possible trouble in the cam output line from loading the range line, hold the follower away from the cam as described in the section on isolating the four shaft lines, page 347.

First examine the counter for jamming or sticking. If the counter operates normally, jamming or sticking in the range line may be caused by: dirty or damaged gears or bearings, including the cam and follow-up bearings, or interference of parts.

If jamming of the range limit stop prevents turning of the range line, refer to the section on the limit stop, page 106.

Dirt and foreign matter can often be removed and minor damage repaired without disassembly.

Trouble found in the follow-up usually requires disassembly. The follow-up can be conveniently removed and treated separately, because its removal upsets only the synchronizing adjustment.



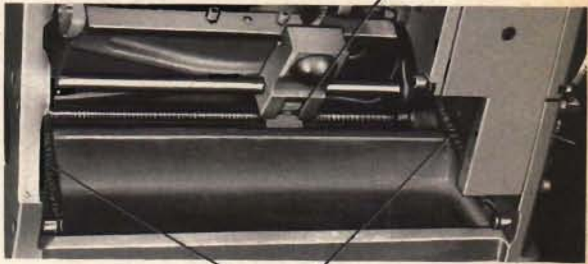
CAM OUTPUT LINE

Cam output line

The cam output line consists of the cam follower, the follower frame, the output sector, and the gearing which joins the range input line to turn the follow-up control. The follower frame can be moved by hand, as explained in the section on isolating the four shaft lines. Moving it will cause the follow-up control to click.

Jamming or sticking in the cam output line may be caused by dirty or damaged gears or bearings. Serious jamming or sticking of the follower frame pivot or the cam follower joint may prevent the springs on the follower frame from holding the guide rail, the cam follower, and the cam in close contact with each other. Then a false signal will be sent to the follow-up control.

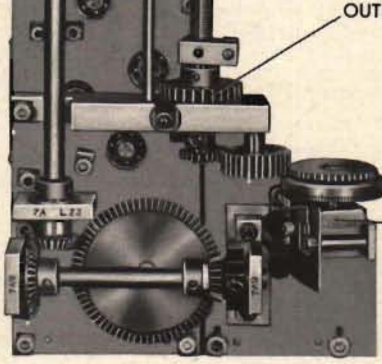
The cam-follower joint, the follower-frame bearings, or the shaft assemblies can usually be cleaned and lubricated while the unit is in the instrument. However, repair or replacement of these parts requires disassembly.



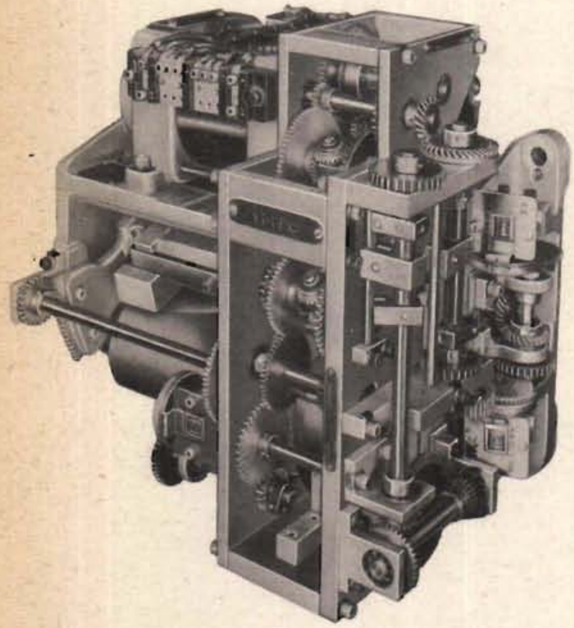
Inspect the cam closely for damage of any kind. A damaged cam should be replaced. Check for misalignment of the cam by determining whether or not its axis is parallel to the follower-arm guide rail, as explained on page 365.

Motor output gearing

The rotor shaft is connected by gearing to the follow-up output gear, a limit stop, a counter, and response gearing back to the follow-up control.



First examine the counter for jamming or sticking. If it operates normally, the trouble may be caused by dirt, damage, or interference at the gear meshes, in the bearings, or in any of the mechanisms in the line. The output gearing can usually be cleaned, lubricated, or repaired while the unit is in the instrument.



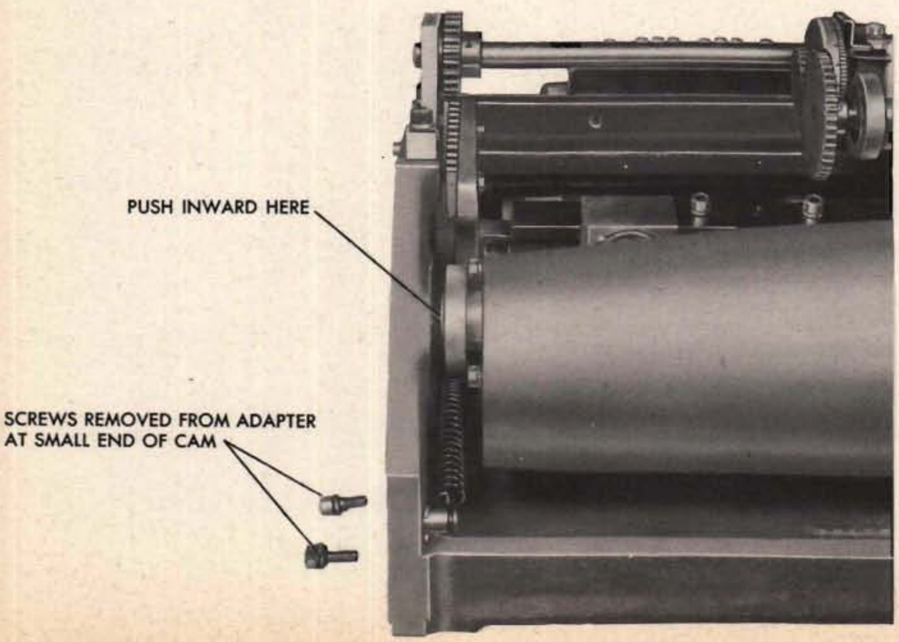
Disassembling the unit

The unit pictured here is the $Vf + Pe$ unit, No. 7A, but the disassembly procedure applies in general to all ballistic computers. The subassemblies can be removed in various orders according to the requirements of different repair jobs. The follow-up, the cam, and the interconnecting gearing can be removed separately. Before the elevation screw and the rocker frame can be removed, however, the cam must be removed.

Removing the cam assembly

1 Remove the two No. 8 screws from the adapters at each end of the cam shaft. Push the adapter at the small end of the cam inward, away from the casting.

2 Carefully lift out the cam.



Disassembling the cam assembly

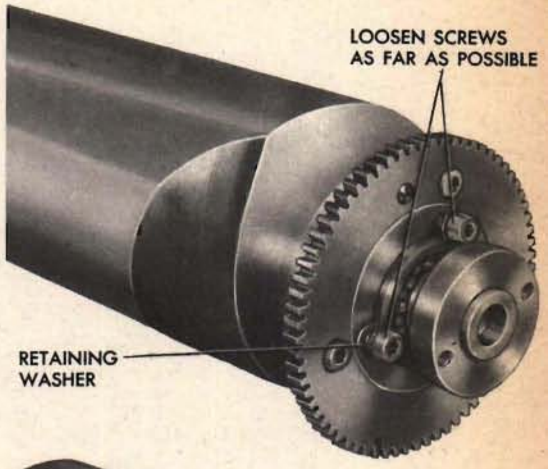
1 Unscrew as far as possible the three No. 8 screws securing the bearing in the gear end of the cam.

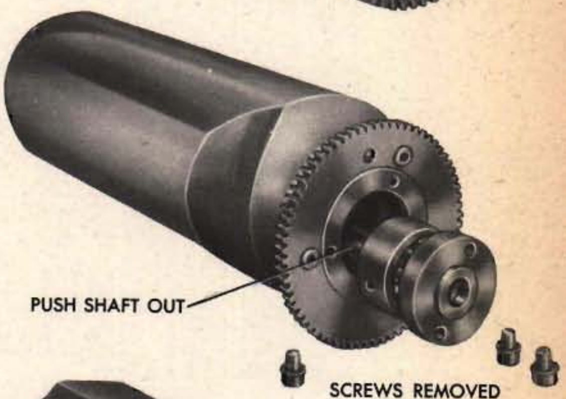
2 Push the cam shaft out as far as it will go. Remove the three No. 8 screws, and carefully slide the shaft out of the cam.

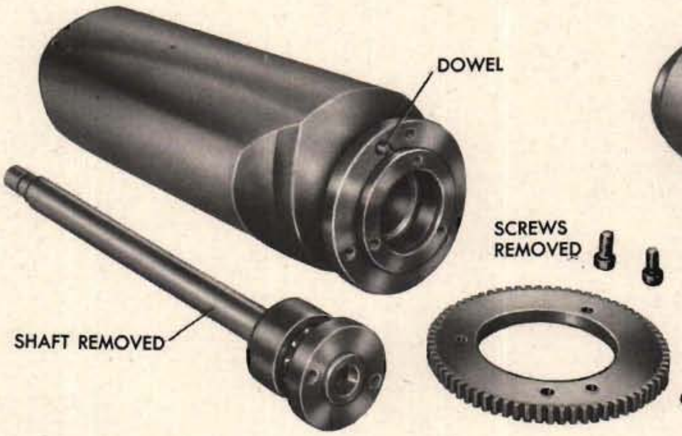
3 Remove the bearing at the small end of the cam by taking out the three No. 8 screws.

4 Remove the three No. 8 screws which hold the doweled gear on the cam, and remove the gear.

5 If it is necessary to remove the bearing or the adapter from the shaft, carefully drive out the adapter taper pin.







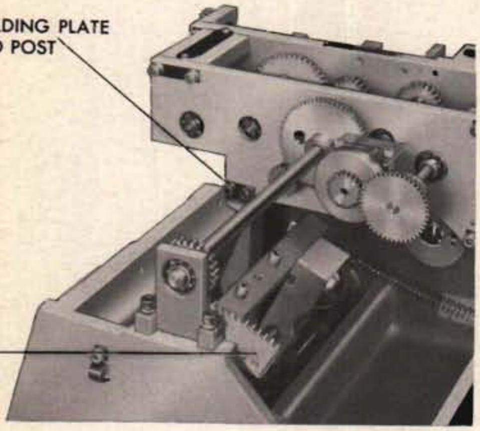
Removing the follow-up

Take out the four No. 10 screws and lift off the follow-up.

Disassembling the follow-up

See the chapter *The Follow-up* in this OP.

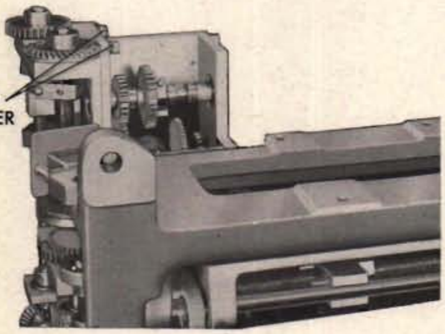
Removing the connecting gearing



1 Remove the two No. 8 screws from the hanger at the sector gear mesh and the two No. 8 screws connecting the plate to the post doweled to the casting.

2 From the back of the plate remove the two No. 8 screws holding the limit-stop hanger.

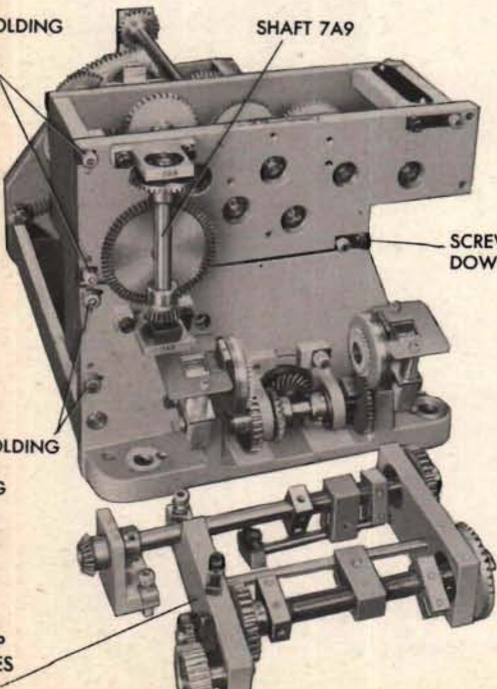
3 Remove the screws holding the limit-stop hangers to the front of the gear box. Lift off the limit-stop assemblies.

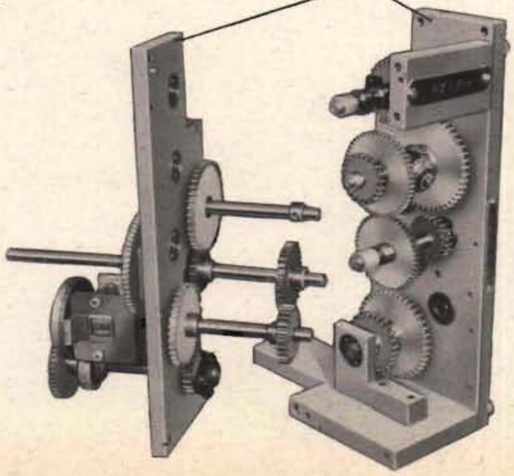


4 Remove shaft assembly 7A9 by taking out the hanger screws.

5 Remove the two No. 10 screws holding the casting and the gear box together and the two No. 8 screws holding the gear box to the doweled post. Back the gear box off its dowels and lift it up

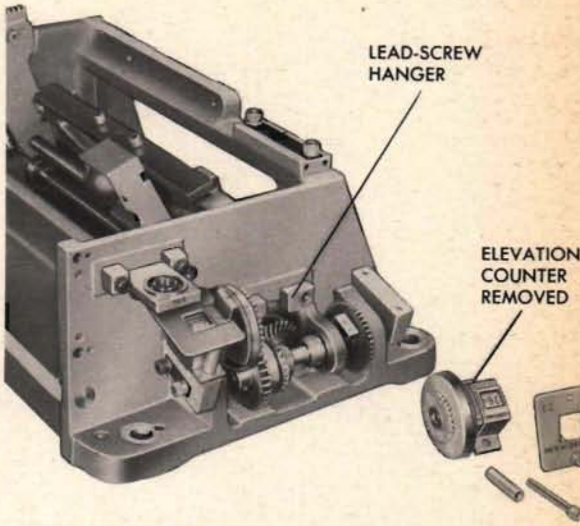
6 To remove any plate-mounted shaft assemblies from the gear box, remove the four No. 10 screws which hold the box assembly together.



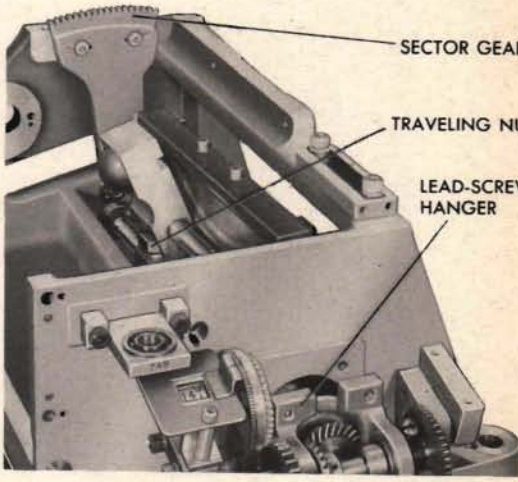


Removing the lead screw and the follower frame

1 Remove the elevation counter by taking out the two No. 6 screws.

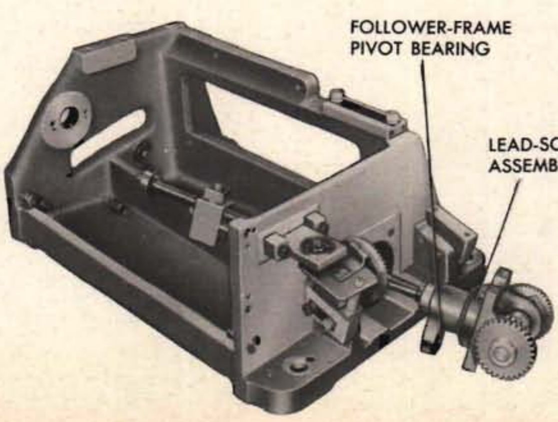


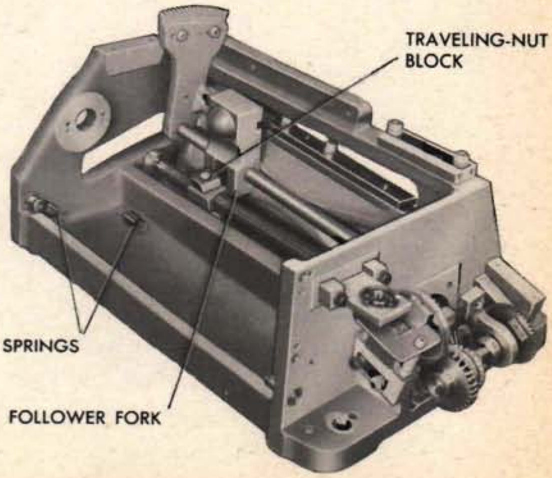
2 Run the traveling nut toward the sector gear and remove the two No. 10 screws which secure the lead-screw hanger to the casting. Pull the lead-screw hanger outward in order to release one end of the follower-frame pivot shaft.



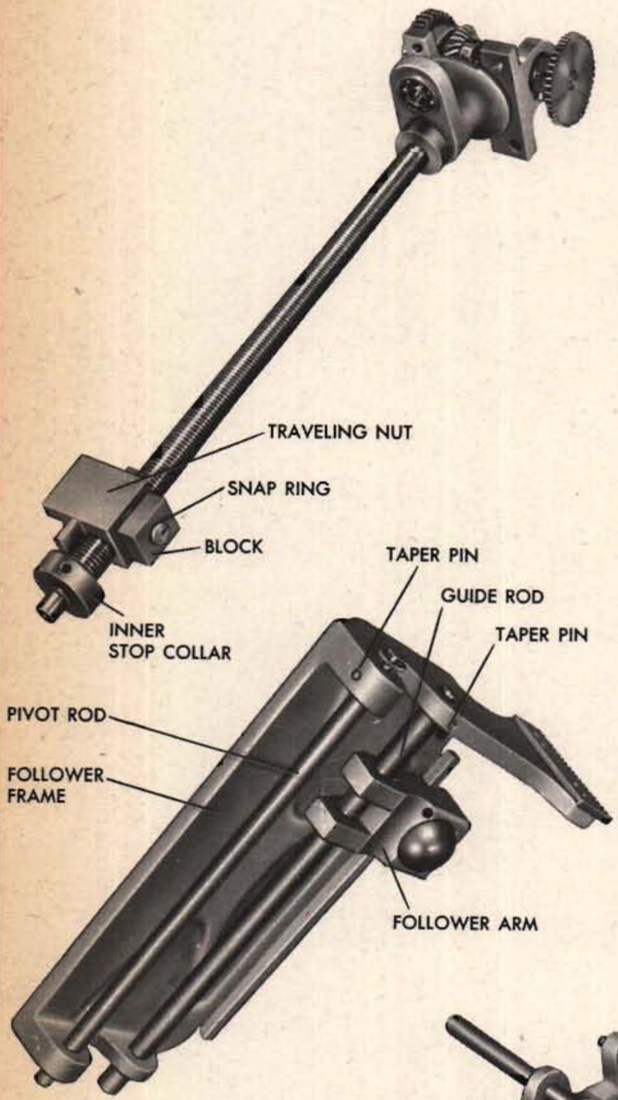
3 Unhook the springs from the follower frame, and turn the traveling nut to remove the traveling-nut block from the follower fork.

4 Pull the follower frame toward the lead-screw hanger in order to release the other pivot from its bearing, and lift out the follower frame. Remove the lead-screw assembly.





Disassembling the lead-screw assembly



1 If necessary, the block on the traveling nut can be removed by taking off the snap ring.

2 To remove the traveling nut, carefully drive the taper pin out of the inner stop collar, pull the collar off the shaft, and turn the nut off the screw.

3 If it is necessary to remove the screw from the hanger, carefully drive out the taper pin from the bevel-gear hub at the end of the screw and pull out the screw.

Disassembling the follower-frame assembly

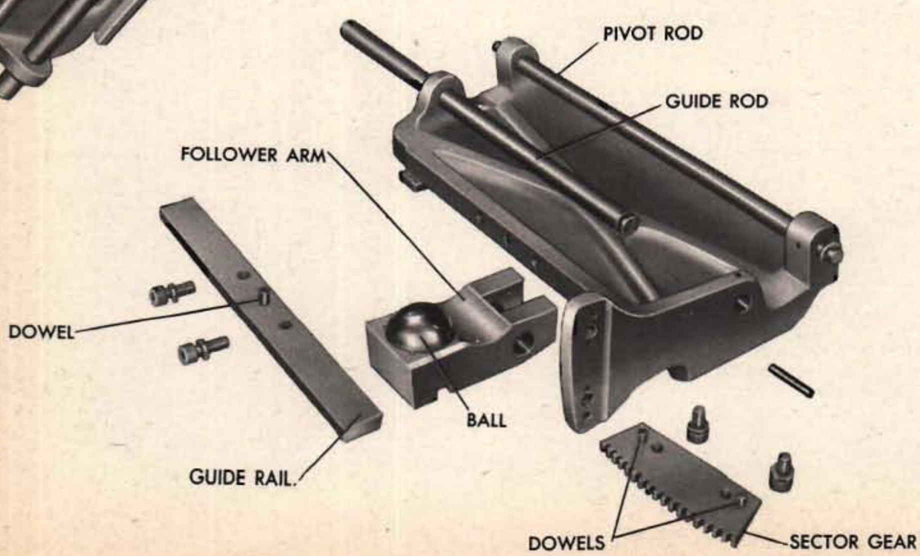
1 To remove the guide rod and follower arm, carefully drive out the guide-rod taper pin.

2 To remove the pivot rod, carefully drive out its taper pin.

3 To remove the ball from the follower arm, tap it lightly from the rear using an aluminum punch.

4 To remove the guide rail, take out the two No. 8 screws.

5 To remove the sector, take out the two No. 8 screws.

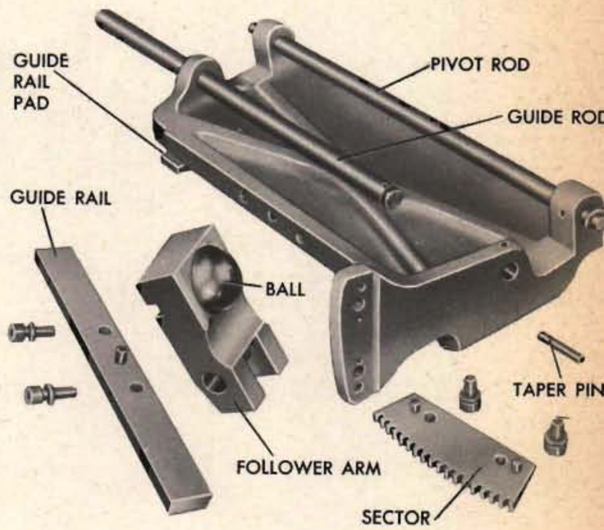


Reassembling each subassembly

In this reassembly procedure, each of the subassemblies is reassembled first. Then all are remounted on the casting.

Be careful to replace every spacer in exactly the same position from which it was removed. Clean and lubricate the cam and all bearings, screws, and gears before they are reassembled.

Reassembling the follower-frame assembly



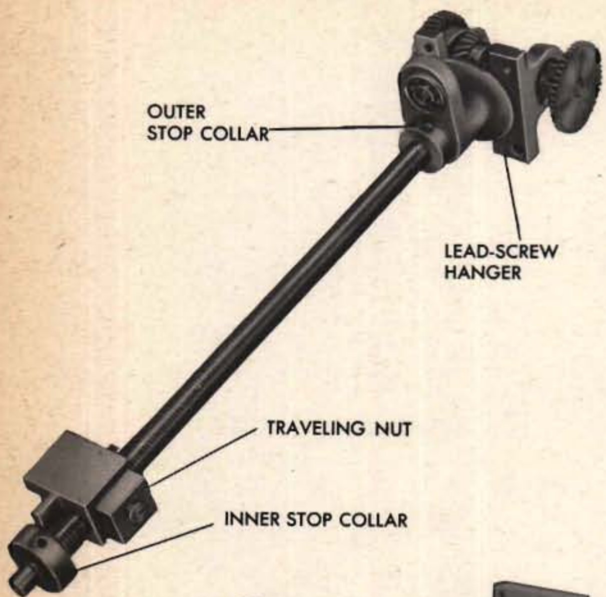
1 Put the ball in the follower arm and stake metal over the edge of the hole to keep the ball in place.

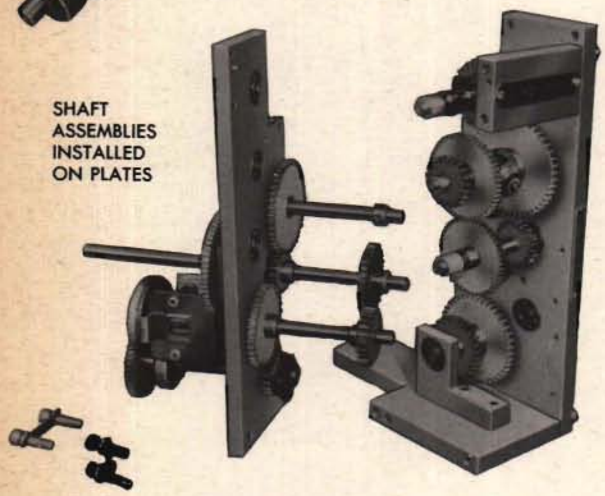
2 Slide the pivot rod in place. Drive in the taper pin and stake it in place.

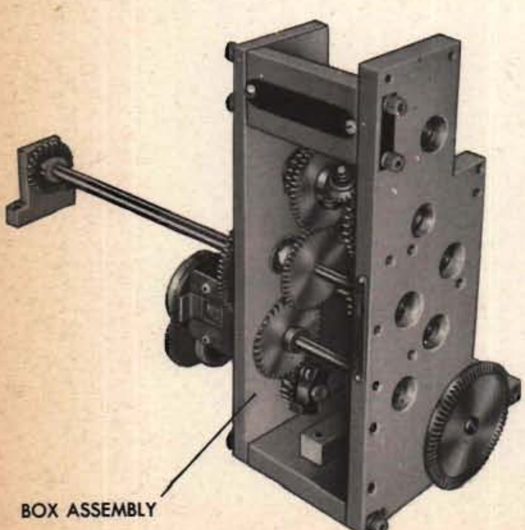
3 Slide the guide rod through the hole in one side of the frame and slide the follower arm onto the rod. Slide the other end of the rod into place. Drive in the taper pin and stake it.

4 Mount the guide rail. Be sure that the dowel is in place, that the rail rests firmly at both ends against the pads, and that the rail is parallel to the guide rod and the pivot rod. Replace and tighten the screws.

5 Position the doweled sector gear on the follower frame and screw it in place. If a new sector is used, do not fit the dowels until the sector mesh has been made.







Reassembling the lead-screw assembly

1 Slide the lead screw through the lead-screw hanger and the bevel-gear hub. Repin the bevel gear.

2 Turn the traveling nut onto the lead screw. Slip the collar on and pin it.

If a new lead screw or stop collar is used, the follower-frame assembly, the lead-screw assembly, and the cam must be temporarily mounted in the casting in order to position the new parts with set screws before pinning. Place a 0.005-inch spacer on the inner end of the lead screw to establish its position with respect to the cam. Keeping a thrust against this spacer, adjust the two stop collars to the limits specified on the assembly drawing. Next fit a spacer between the outer stop collar and the bearing so that there is no end shake in the lead screw. Remove and discard the 0.005-inch spacer which was on the inner end of the lead screw and again eliminate end shake, this time by fitting a spacer between the bevel gear and the outer bearing. Thus the end play of the lead screw is controlled at the hanger end.

Reassembling the gear box

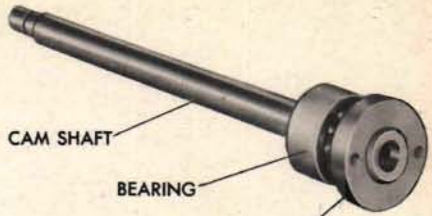
1 Refer to the assembly drawing for the correct positions of shafts and gears. Mount the shaft assemblies on the plates, being very careful to use the proper spacers.

2 Fit the box assembly together.

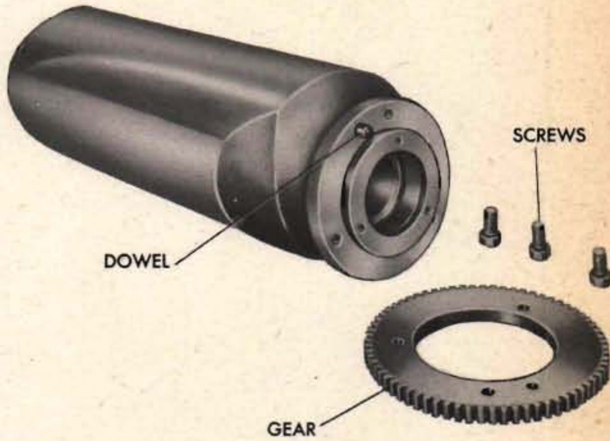
If a new gear or shaft is used, position the parts and hold them with set screws for drilling and pinning.

Reassembling the cam assembly

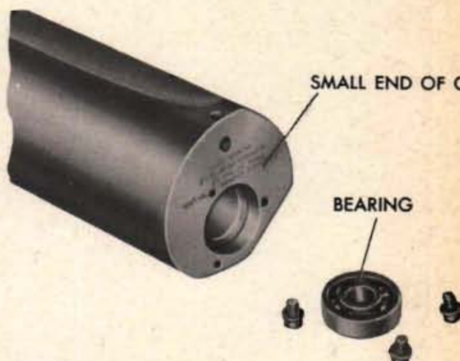
1 Fit the wide bearing and the adapter on the gear end of the cam shaft so that there is a minimum of end play. Repin the adapter.



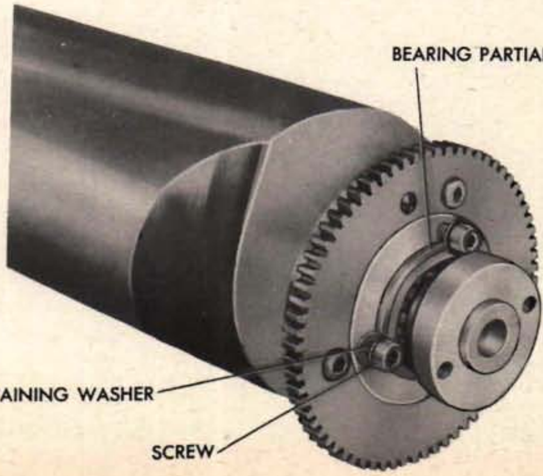
2 Place the gear on the cam so that the dowel goes through the dowel hole in the gear.

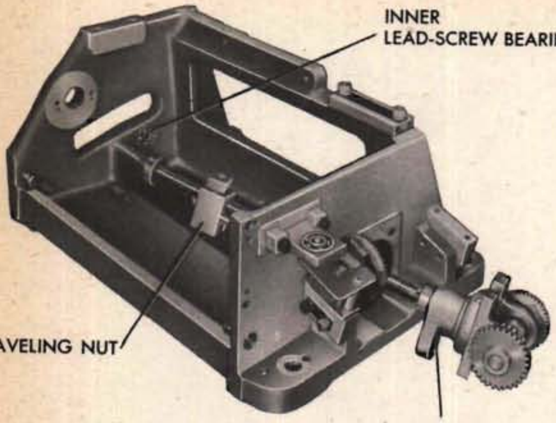


3 Seat the narrow bearing in the small end of the cam and secure it with the three screws and retaining washers.



4 Slide the shaft into the cam, and partially seat the bearing as shown. Insert the three screws and turn them until the retaining washers touch the bearing. Then seat the bearing completely and tighten the screws.



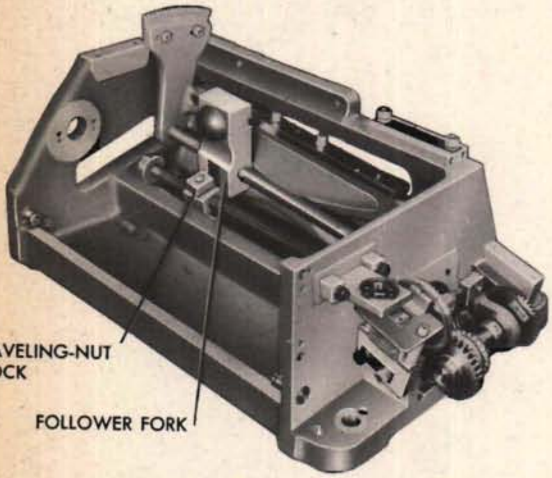


Reassembling the unit

As the subassemblies are mounted in place, position the shaft assemblies so that the gears mesh freely with an absolute minimum of lost motion.

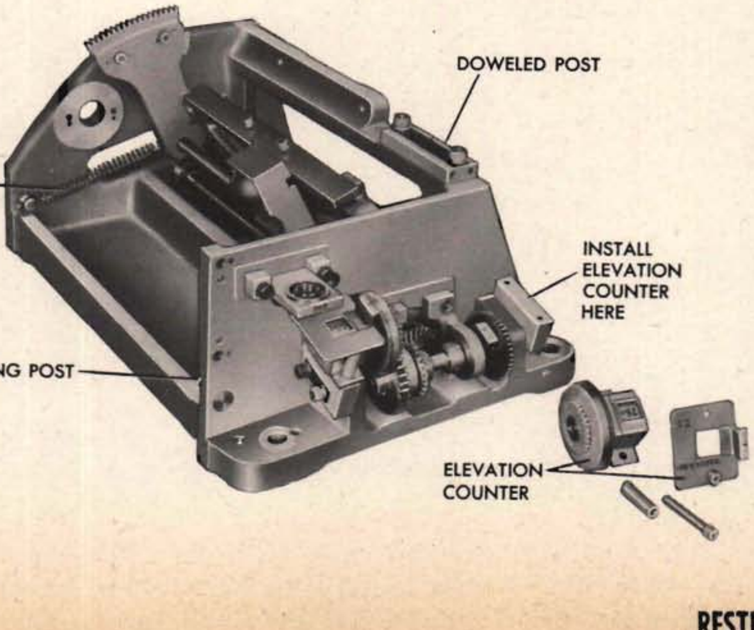
1 With the traveling nut at the inner end of the lead screw, push the screw through the casting as shown.

2 Put the follower-frame assembly into position in the casting and slip the follower fork over the block on the traveling nut. Fit the inner end of the follower-frame pivot into its bearing. Then manipulate the lead-screw assembly so that the outer follower-frame pivot goes into the bearing on the lead-screw hanger, while the inner end of the lead screw goes into its inner bearing. Replace the two No. 10 screws in the lead-screw hanger.



3 Hook the two springs to the follower frame and the casting.

4 Make sure that the long graduations of the elevation-counter drum dial are aligned with the counter numbers and check the assembly clamp on the dial for tightness. Mount the counter assembly.



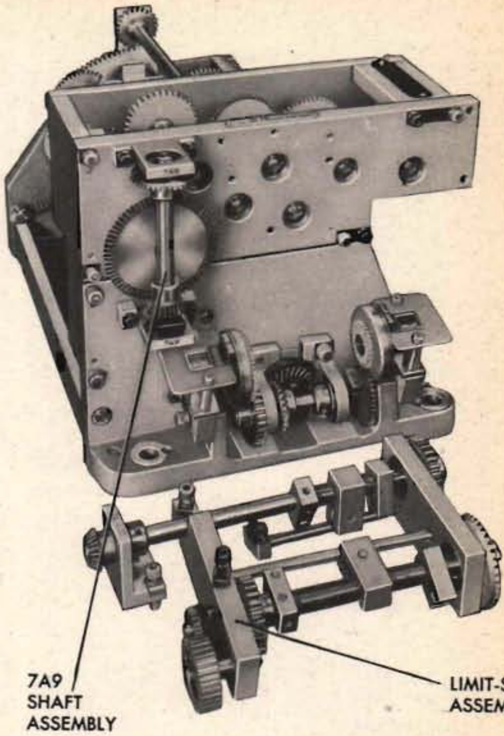
5 Mount the gear box on its dowels and over the doweled post still attached to the casting.

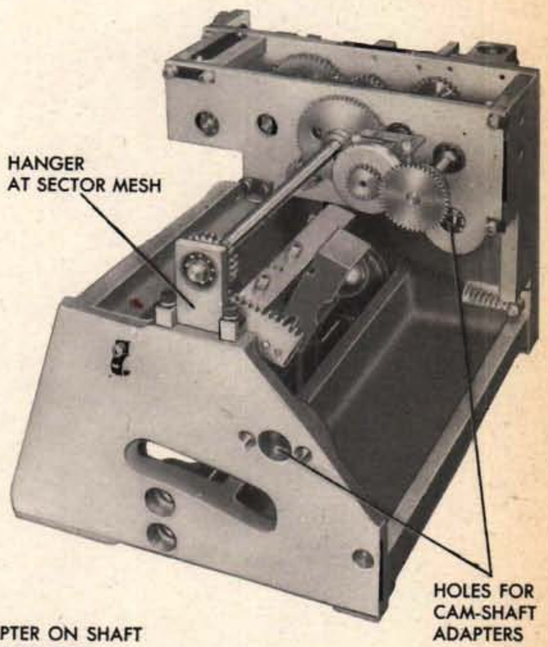
6 Mount the limit-stop assemblies, and shaft assembly 7A9.

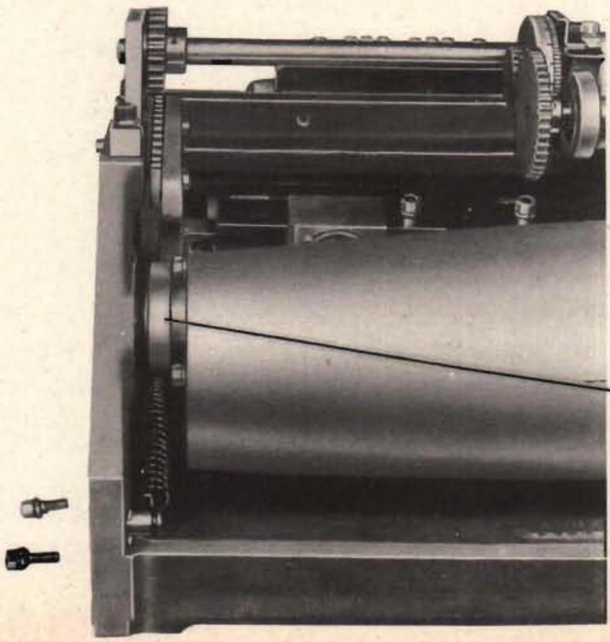
7 Secure the hanger of shaft assembly 7A10 at the sector mesh.

8 Mount the follow-up.

9 Push the adapter onto the shaft at the small end of the cam. Install the cam assembly and secure the adapters through the casting at each end.







Bench checking the unit

Stand the ballistic computer in the position in which it is mounted in the instrument.

LONG GRADUATION ALIGNED WITH FIGURES

1 Check the unit against the assembly drawing.

2 Check the gearing for ease of operation and lost motion.

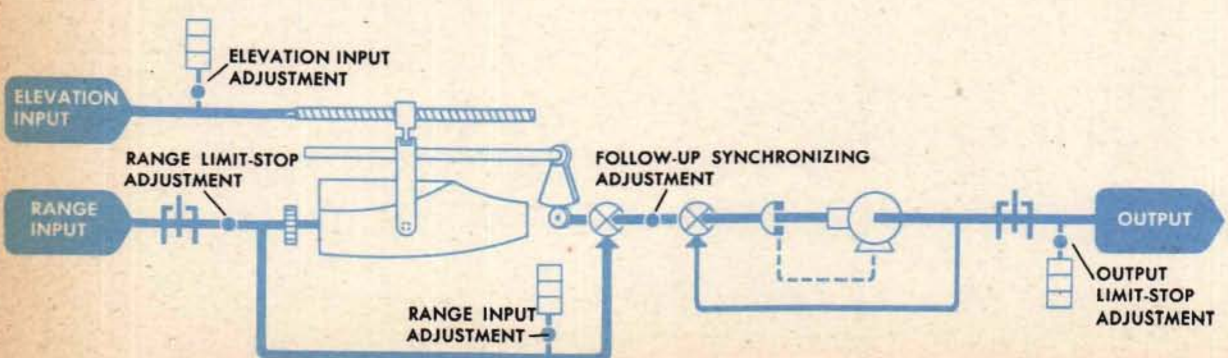
3 Check all the assembly clamps for tightness.

4 Check the counter drums for alignment of the long graduations with the figures.

5 Apply 110-volt 60-cycle power to the single and double-letter bus bars of the motor terminal block. Check that the follow-up output shaft follows the dictates of the input shaft.

DATA ON SMALL END OF CAM

6 Check the data stamped on the small end of the cam to make sure that the cam is the correct one for the instrument being repaired.



Adjustment and test data

The ballistic computer should be fully readjusted to give a satisfactory set of test readings before being installed in the instrument.

First obtain the correct ballistic computer adjusting and testing information for the particular Mark and Mod of the instrument being repaired. For the Computer Mark 1, adjusting instructions are available under *Factory Adjustment Procedure,* OP 1064A, and test forms may be obtained from the NIO final acceptance test sheets. For the Range Keeper Mark 10, all the necessary information for both adjusting and testing may be found in the applicable OD.

TYPICAL BALLISTIC COMPUTER TEST

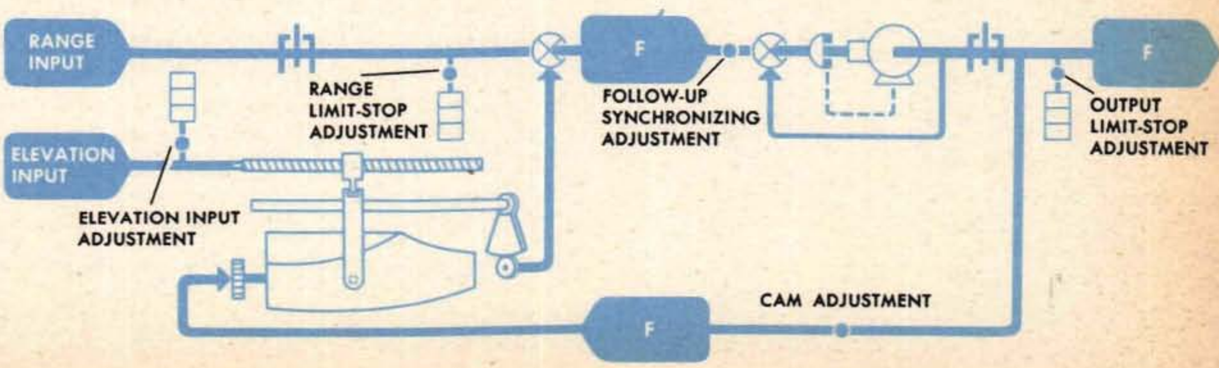
(Vf+Pe) (MIN.)

R2	500 YDS.			3000 YDS.			6000 YDS.			8000 YDS.		
E2	CALC.	READ.	ERROR	CALC.	READ.	ERROR	CALC.	READ.	ERROR	CALC.	READ.	ERROR
0°	82.6			105.4			249.8			400.7		
30°	71.0			95.0			233.9			381.5		
50°	51.8			69.1			174.9			287.5		
70°	27.5			36.0			92.6			151.3		
TOTAL ERROR												
R2	10000 YDS.			12000 YDS.			14000 YDS.			16000 YDS.		
E2	CALC.	READ.	ERROR	CALC.	READ.	ERROR	CALC.	READ.	ERROR	CALC.	READ.	ERROR
0°	613.3			898.7			1259.4			1720.8		
30°	589.3			885.9								
50°	450.2			711.8								
70°	238.1											
TOTAL ERROR												

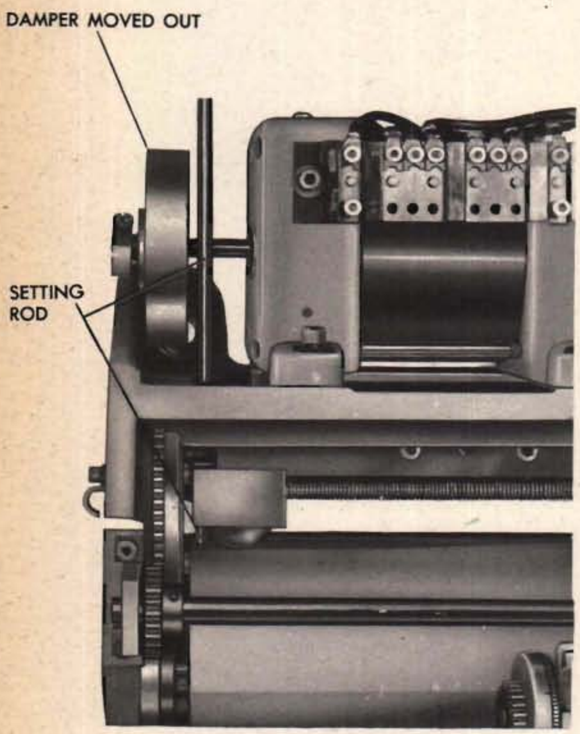
GRAND TOTAL ERROR (25 READINGS) ________ MIN.
AVERAGE ERROR ________ MIN.
MAJORITY ERROR ________ MIN.
MAXIMUM ERROR ________ MIN.

ALLOW. AVG. & MAJ. ERROR = 2 MIN.
ALLOW. MAX. ERROR = 6 MIN.

REGENERATIVE FUZE BALLISTIC COMPUTER USED IN COMPUTER MK 1, SER. NOS. 781 AND HIGHER



Adjusting and testing a ballistic computer



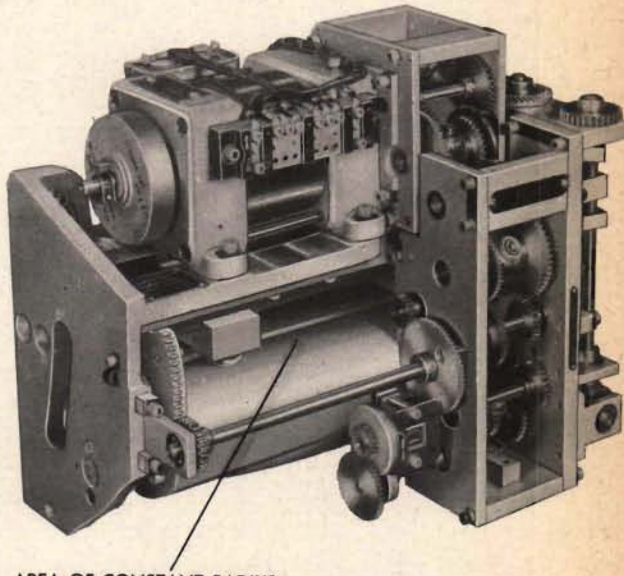
Before starting the adjustment procedure on a ballistic computer which has been repaired, loosen all the adjustment clamps.

The adjusting instructions call for insertion of a 3/16-inch setting rod through the follower and cam. Before attempting to insert the setting rod, loosen the damper and move it out toward the end of the motor shaft. This will provide a clear path for the setting rod. Be sure that the 3/16-inch setting rod is a free fit in the follower and cam. If not, it should be polished down until there is no danger of its jamming.

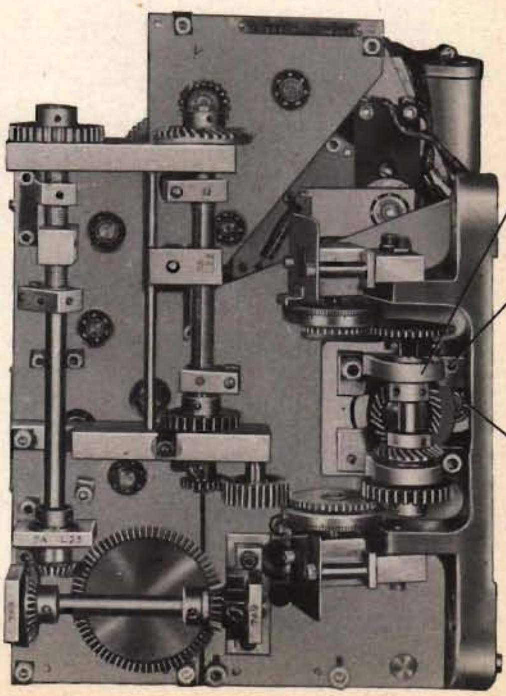
When the adjustments have been completed, take a full set of test readings. Following the test form for the particular ballistic computer being serviced, set *E2* at the first value given and hold it with a wedge. Position the range counter at each of the values listed for that elevation, recording the output counter readings on a test form. Repeat this for each value of *E2,* and when all the readings have been taken, compute the errors. If the errors exceed the allowable values given on the test form, they may be improved by refining the adjustment between the cam and its input or the adjustment between the lead screw and its input.

Correcting cam and follower alignment

If the test readings are still unsatisfactory after refining the adjustments as much as possible, analyze the errors for nonparallelism between the cam axis and the guide rail. This trouble will be indicated if the errors for a given range build up in a fixed direction as elevation is changed from 0° to 90°.



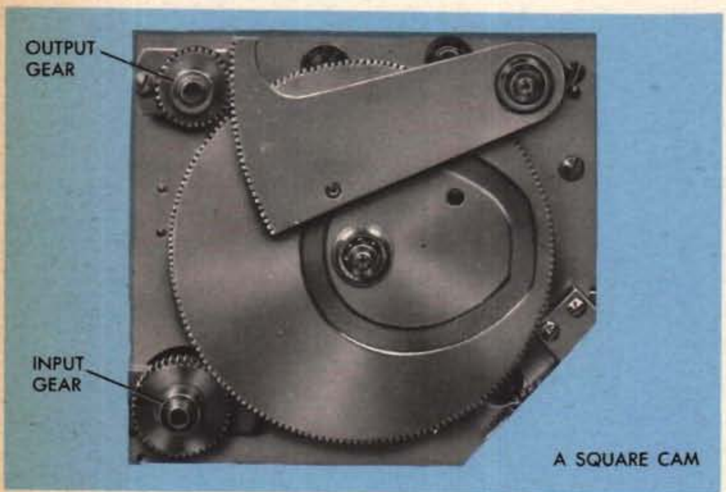
To check this further, rotate the cam so that the follower is on the constant-radius portion, and lock the cam. Change elevation from one limit to the other while observing the output counter. Any movement of the counter indicates nonparallelism.



To correct this condition, remove the upper dowel from the lead-screw hanger and make the two No. 10 screws slip-tight. Pivoting the hanger on its remaining dowel, move it in the direction which improves the test readings. When the best position for the lead-screw hanger is determined, tighten the screws and fit an oversize dowel in the upper dowel hole.

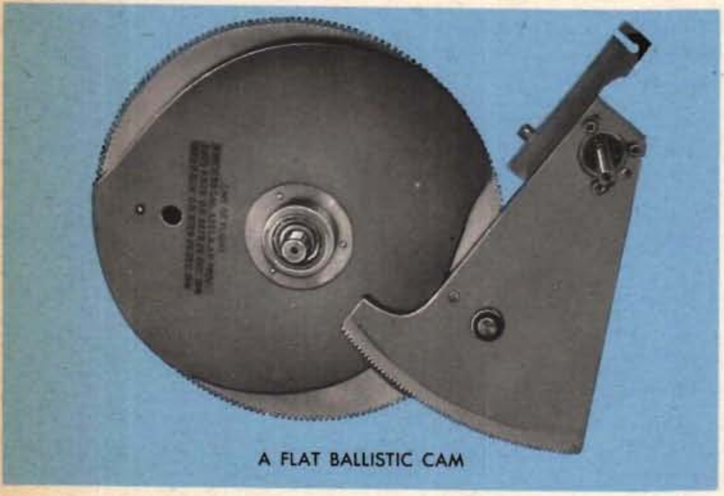
When the adjustments are complete and the test readings satisfactory, the range limit stop should be rechecked. Also, make sure that the elevation line can be turned from 0° to 90°.

COMPUTING CAMS



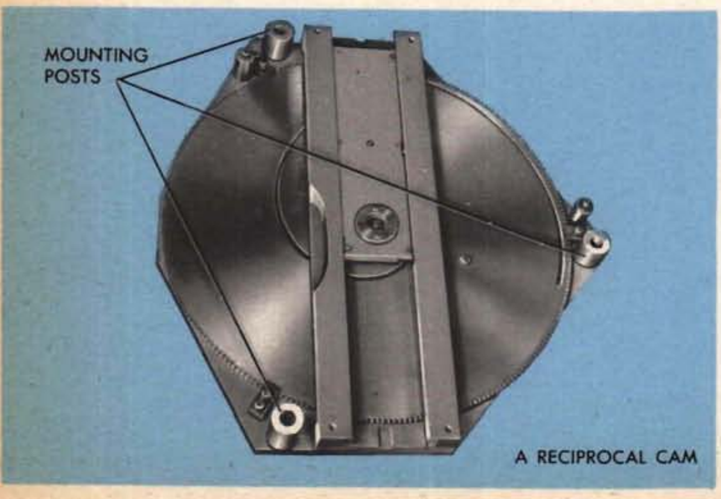
A SQUARE CAM

The five most common computing cams are: square, flat ballistic, reciprocal, secant, and barrel ballistic. The barrel ballistic cam is described in the chapter on ballistic computers, page 342. Since the construction of the reciprocal and secant cams is similar, their repair procedure is identical. This chapter gives the repair procedures for square, flat ballistic, and reciprocal cams.


A FLAT BALLISTIC CAM

A square, flat ballistic, or reciprocal cam is usually mounted as part of another unit. Before the cam can be disassembled for repair, it is often necessary to remove the other unit from the instrument before separating the cam assembly from it.

The reciprocal cam is sometimes mounted as an independent unit with its own input and output gearing. It can be removed from the instrument by taking out the screws which hold its three posts to the instrument.

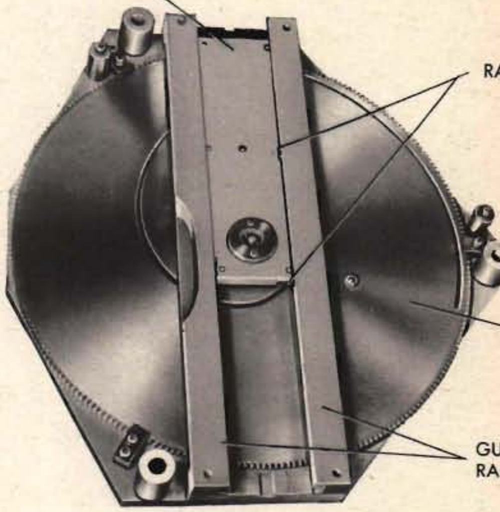


A RECIPROCAL CAM

Minor repairs can sometimes be made without removing the unit from the instrument. If the unit must be removed for repair, consult the instrument OP for instructions.

Typical symptoms

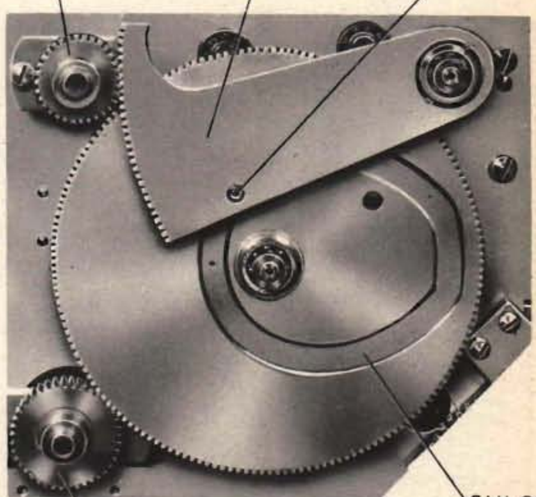
If a test analysis and unit check tests indicate that the unit is not operating properly, look for one of the following typical symptoms:



JAMMING: The cam cannot be turned by hand.

STICKING: The cam resists turning past a certain point or points, or turns sluggishly.

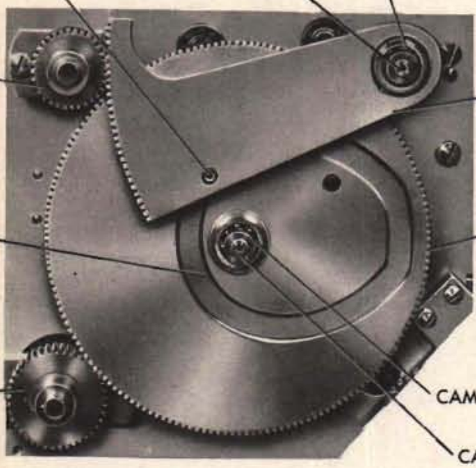
EXCESSIVE LOST MOTION: There is too much play between a cam groove and follower, the input and output gear, or rack rollers and guide rails.



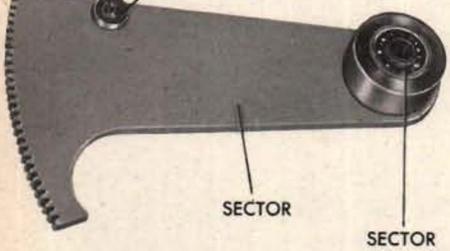
SLIPPING: Moving the input gear does not move the output gear; or turning the cam does not position the sector or the carriage.

Locating the cause

Jamming or sticking



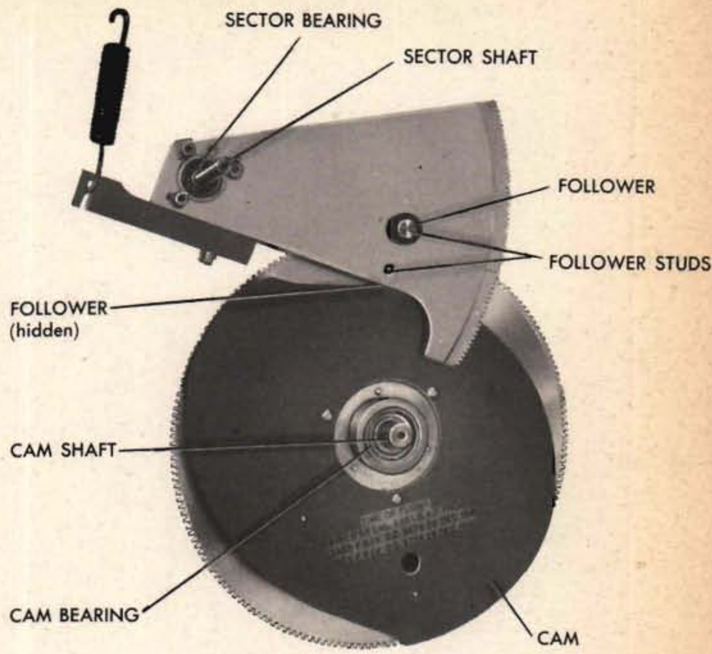
A computing cam may jam or stick because of a dirty or damaged cam edge or groove, follower, or follower stud; or because of dirty or damaged carriage gear teeth, cam or sector gear teeth, bearings, or guide rails.



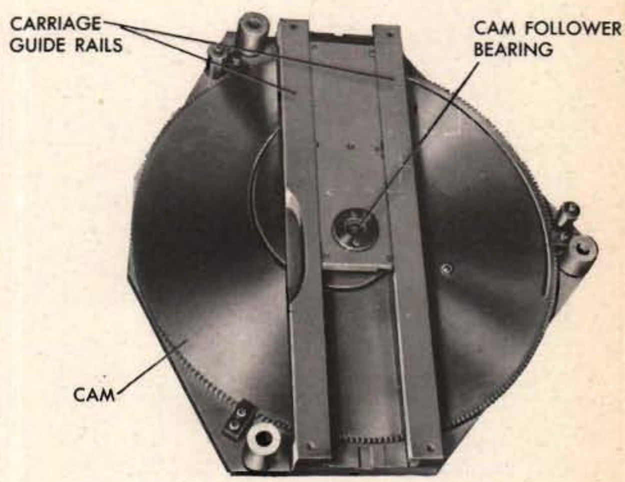
If a square cam jams or sticks, look for a dirty or burred cam follower, a bent cam follower stud, or a dirty or damaged cam groove. Examine the input and output gears and the cam and sector gear teeth for dirt or damage. Also inspect the bearings on which the cam and the sector are mounted. Dirty bearings should be cleaned and damaged ones replaced.

Bent cam or sector shafts may also cause jamming or sticking. The unit must be disassembled in order to remove and straighten these shafts.

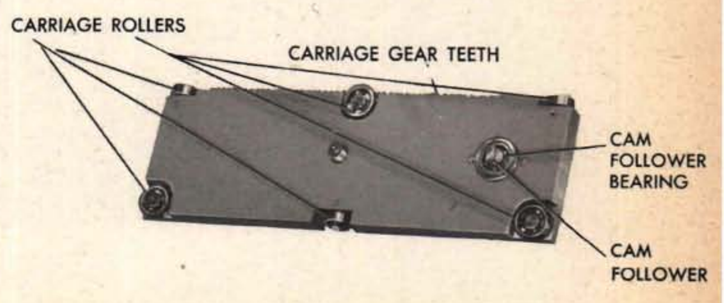
If a flat ballistic cam jams or sticks, the edge of the cam follower may be dirty or damaged. A badly damaged cam must be replaced. Look also for dirty or damaged cam or sector bearings, damaged gear teeth, a damaged follower, or a bent follower stud, cam shaft, or sector shaft.

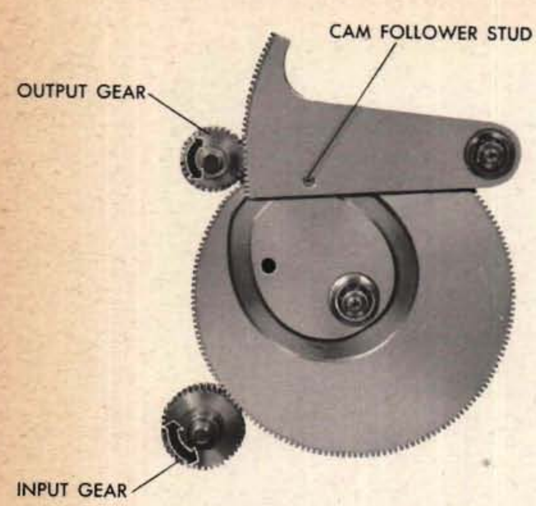


If a reciprocal cam jams or sticks, the cam or follower bearing, the follower, or the cam or carriage gear teeth may be dirty or damaged.



Examine the six carriage rollers and the carriage guide rails for burred surfaces or dirt. The carriage and rails must be removed from the unit for repair. The unit must be removed in order to inspect the cam follower bearing for dirt or damage.

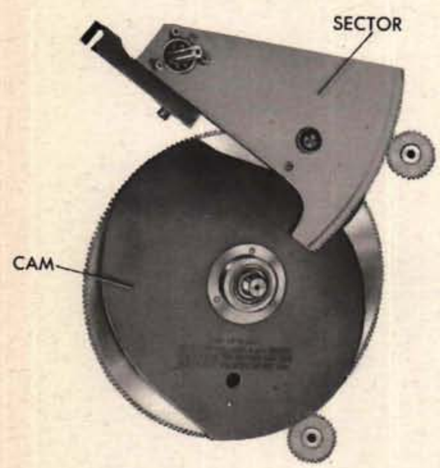




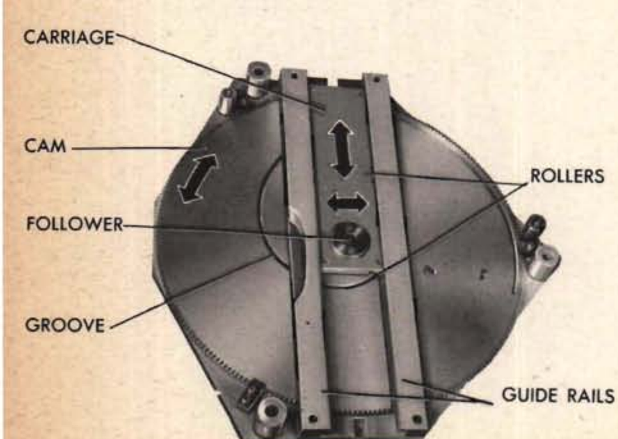
Excessive lost motion

Excessive lost motion between the input and output gears or between the cam and the sector or carriage may be caused by a loose or worn follower or by damaged gear teeth. On a reciprocal cam, worn or improperly adjusted carriage rollers or worn guide-rail grooves may cause excessive lost motion between the carriage and the guide rails.

On a square cam, if there is too great a lag between the turning of the input and output gears, inspect all gear teeth and the cam follower for wear. Look also for looseness of the follower on the stud.



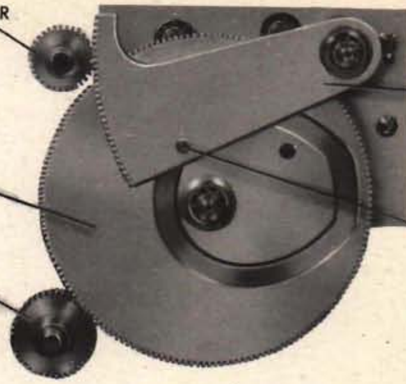
On a flat ballistic cam, too great a lag between the turning of the cam input gear and the moving of the sector output gear may be caused by worn gear teeth.



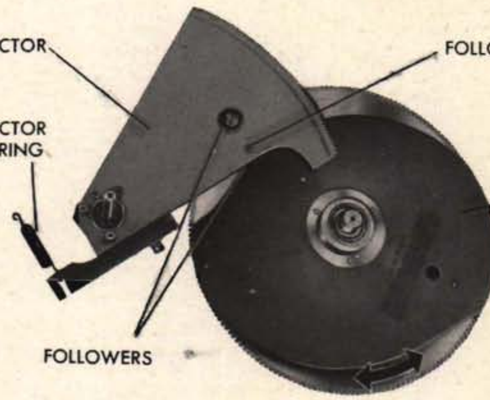
On a reciprocal cam, too great a lag between the turning of the cam input gear and the moving of the carriage is probably caused by worn gear teeth, a worn follower or groove, or excessive lost motion between the carriage and the guide rails. Excessive lost motion between the carriage and the guide rails may be caused by worn or loose carriage rollers or by worn guide rails. It is easier to inspect or repair the carriage gear teeth when the carriage is disassembled.

Slipping

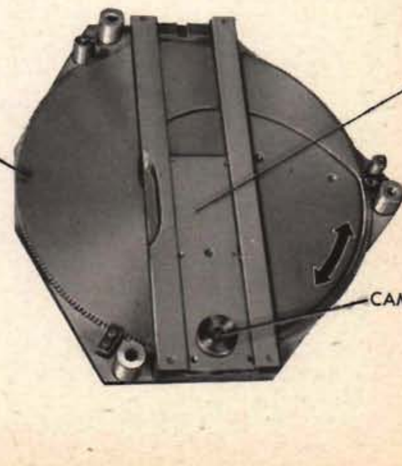
On a square cam, slipping between the input and output gears or between the cam and the sector may be caused by a sheared or missing follower stud.

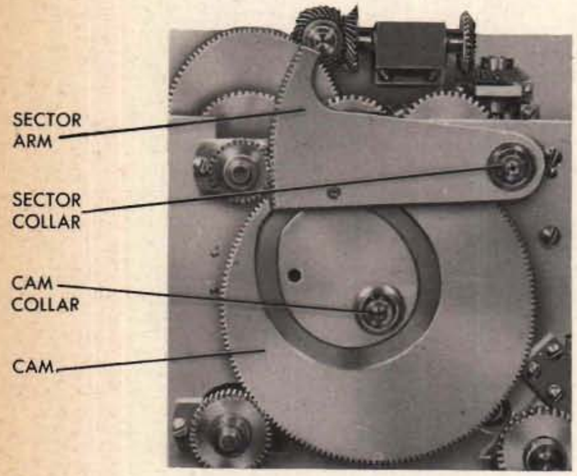


On a flat ballistic cam, if the sector does not move when the cam is turned, the cause may be either a sheared or missing follower stud or a weak or broken sector spring.



On a reciprocal cam, if the carriage does not move when the cam is turned, the cause is probably a sheared or missing follower.

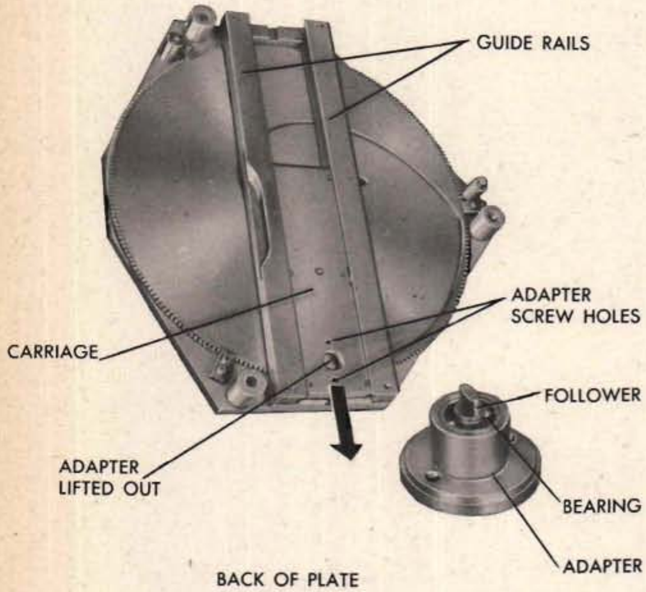




Disassembling the units

The square cam is part of a larger unit. To disassemble the square cam, drive the taper pins out of the collars and pull the collars, the sector arm, and cam off their shafts.

The flat ballistic cam is also part of a larger unit. To disassemble the cam and sector, consult the instrument OP for instruction.

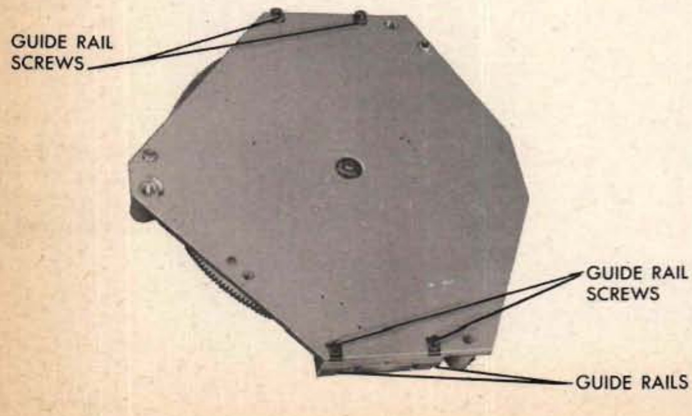


The reciprocal cam is disassembled as follows:

1 Remove the two adapter screws and lift out the adapter.

2 Slide the carriage out at one end of the rails.

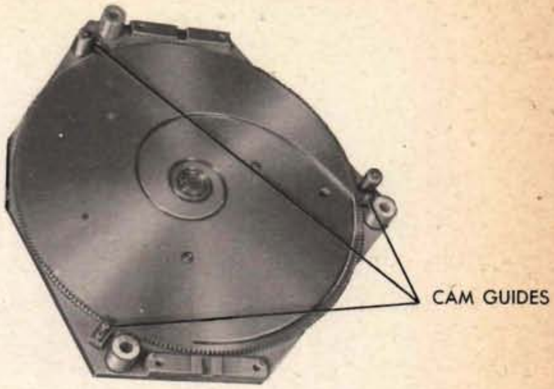
BACK OF PLATE



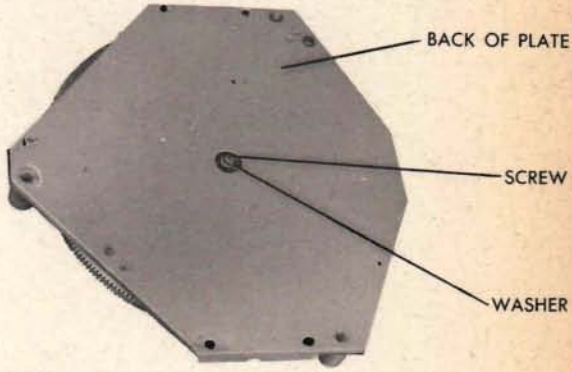
3 From the back of the plate, remove the four screws holding the guide rails.

4 Lift off the guide rails.

5 Remove the three cam guides.

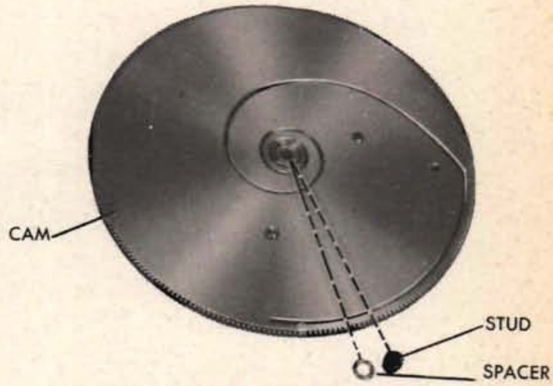


6 Remove the screw in the cam stud from the back of the plate. Tag the washer.



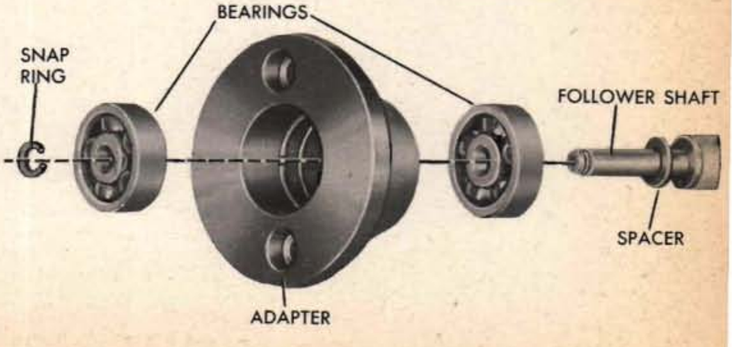
7 Remove the cam stud and spacer. Tag the spacer.

8 Lift the cam off the plate.

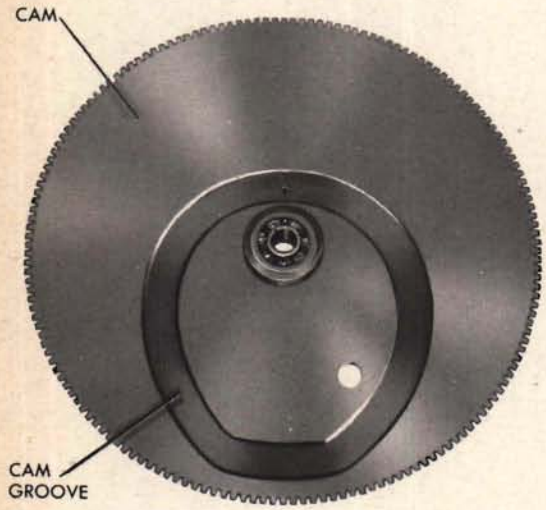


9 Remove the snap ring and carefully drive the follower shaft out of the two bearings. Tag the spacer.

10 Push the bearings out of the adapter.

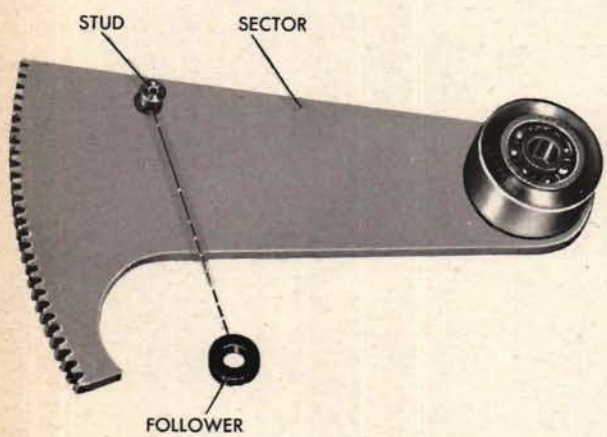


Repairing the parts



Repairing a cam

A cam groove that is only slightly damaged may be repaired by burnishing the surfaces. See page 238. If a cam groove is badly damaged, the cam must be replaced. Burnishing a badly burred groove will enlarge the groove and cause excessive lost motion.



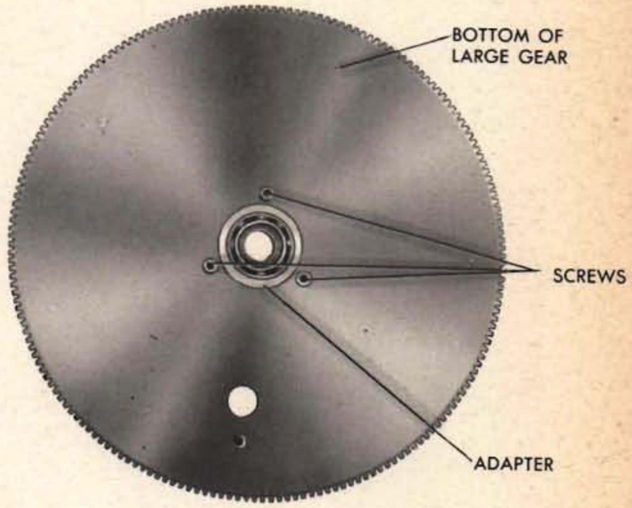
Repairing a follower

On a flat ballistic or square cam, if a follower binds on its stud, disassemble the follower and polish the stud. Keep trying the follower on the stud until it turns freely but without excessive lost motion. Then lubricate the stud and mount the follower.

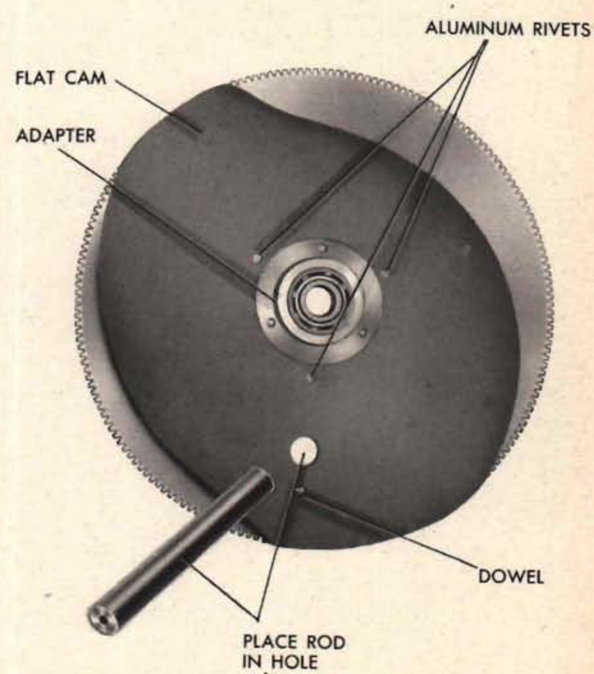
A slightly bent follower stud can be straightened, but a badly bent one must be replaced.

A burred follower should be polished very carefully because any reduction in diameter will cause excessive lost motion between the follower and groove.

Replacing a flat ballistic cam or gear



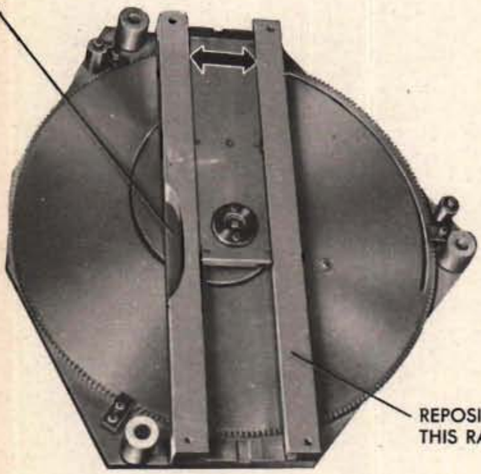
If the edge of a flat ballistic cam or the teeth of the large gear are damaged, the part must be replaced. Fasten the adapter to the large gear with three screws in the back of the gear.



Place the flat cam on the adapter after polishing both surfaces, if necessary, to make a close fit. Insert a short length of rod through the holes of the cam and gear. Dowel the flat cam to the gear and then rivet them together with three aluminum rivets. Clean and lubricate the two large bearings before remounting them in the adapter. Consult the assembly drawing before replacing a cam or gear.

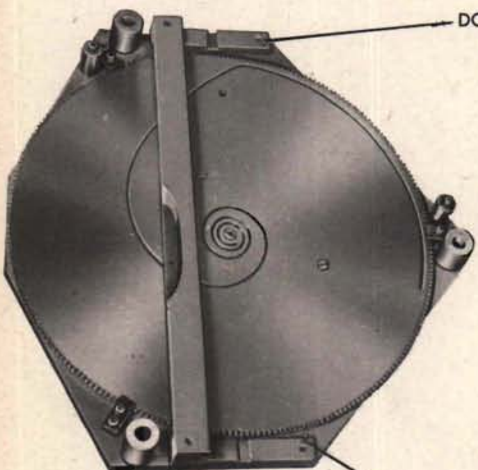
Repairing gear teeth

Slightly burred gear teeth can be repaired by stoning off the burrs. If the teeth on a gear, cam, sector, or carriage are badly damaged, however, the part should be replaced.



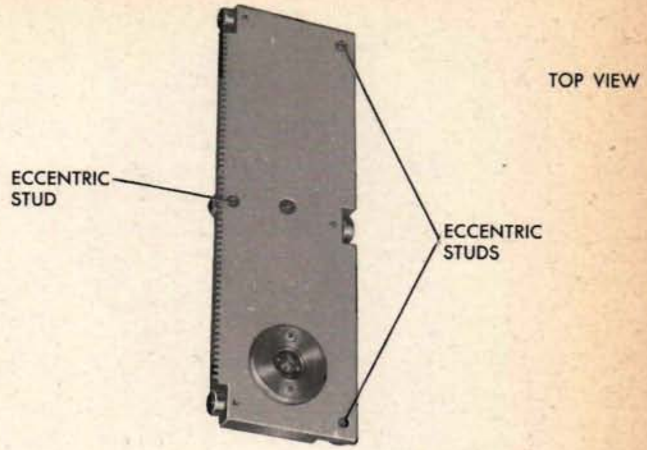
Eliminating carriage side play

In a reciprocal cam, if there is too much play between a carriage and its guide rails, it is usually advisable to eliminate the play by repositioning the guide rail which has no cut-away section. Moving the rail with the cut-away section might disturb the mesh between the carriage-rack gear teeth and the output gear.

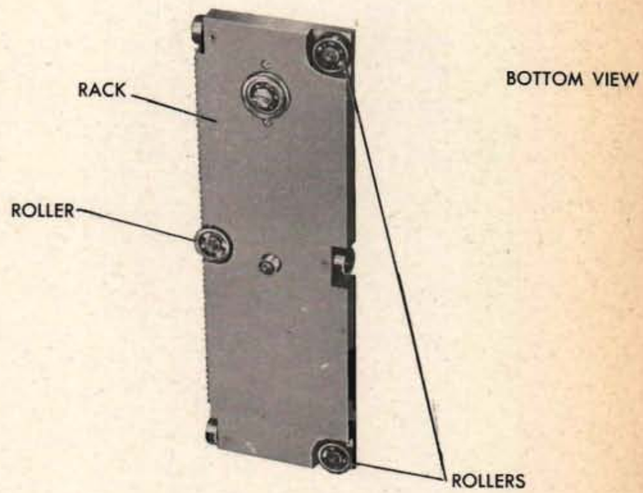


Remove the carriage and rail to be repositioned. Drive the dowels out of the plate. Mount the carriage and rail so that the carriage can be moved freely throughout its travel without excessive lost motion. Be sure that the rails are exactly parallel. Tighten the screws and redowel with oversize dowels. See *Basic Repair Operations,* page 74.

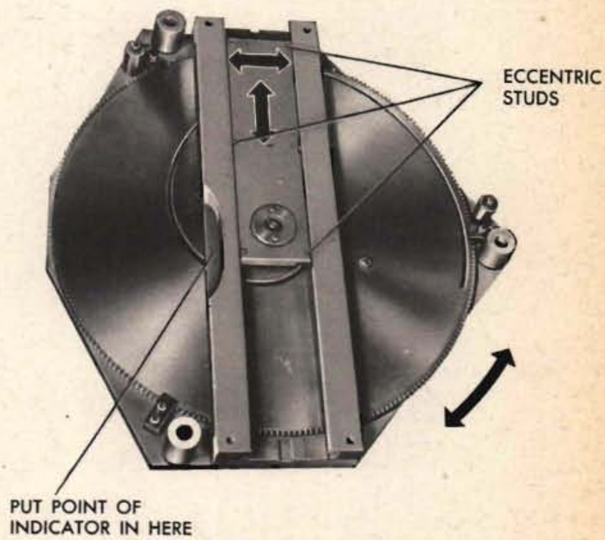
If the carriage rollers have eccentric studs, however, excessive lost motion can be eliminated by adjusting the studs. Carefully adjust the studs by turning them a little at a time. Keep turning the studs until the carriage moves freely with a minimum of lost motion throughout its travel.



When adjusting the stud of the single roller on the rack side of the carriage, be careful not to spoil the rack teeth mesh. When adjusting the two studs on the opposite side of the carriage, be careful not to cock the carriage between the rails.



To check the position of the carriage, mount a dial indicator against the rack teeth and move the carriage through the full length of its travel. For allowable error, consult the assembly drawing. When the carriage has been positioned satisfactorily, remove it and stake the studs.

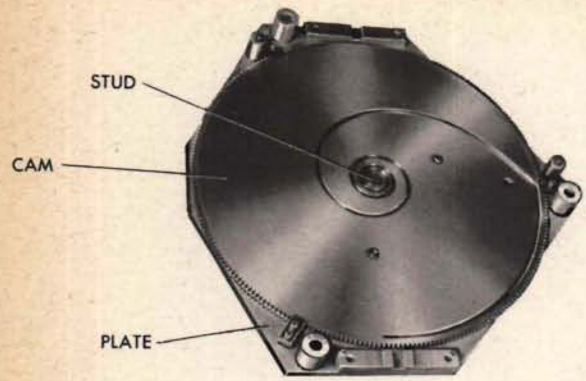


Reassembling the units

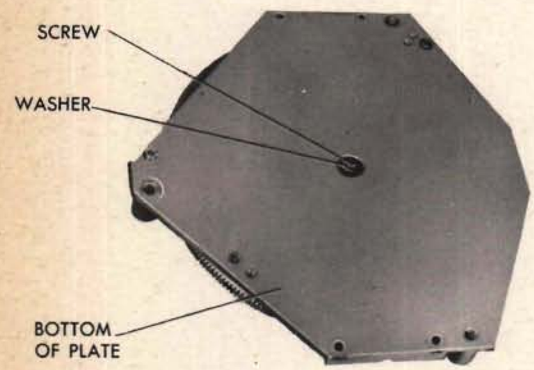
To reassemble the *square cam,* mount the cam and the sector on their shafts, pin the collars, and stake the pins.

To reassemble the *flat ballistic cam,* consult the instrument OP.

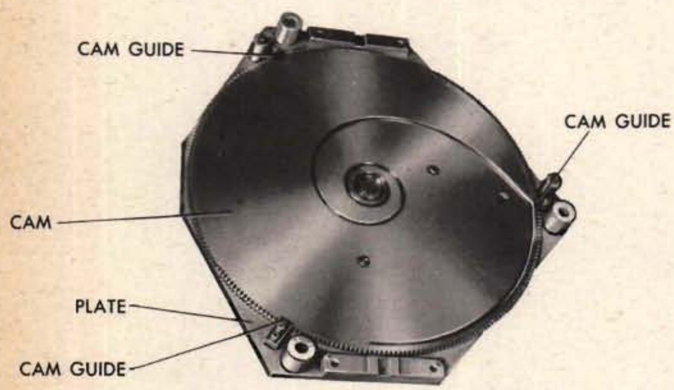
To reassemble the *reciprocal cam,* follow this procedure:



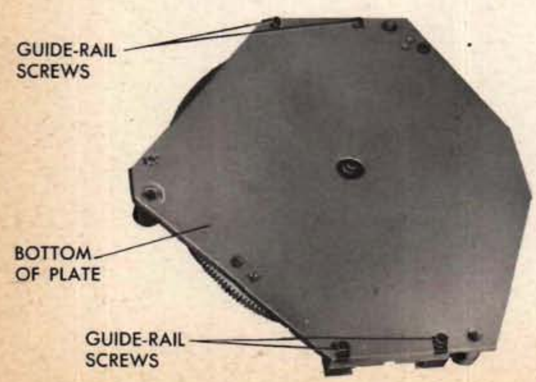
1 Mount the cam on the plate with the spacer between them. Insert the stud.



2 Hold the washer in position over the stud on the bottom of the plate and fasten the screw.



3 Mount the three cam guides and fasten the screws.



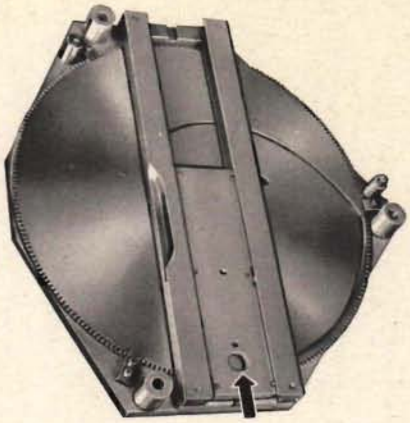
4 Mount both rails and fasten the four guide-rail screws from the bottom of the plate.

5 Slide the carriage in position from one end of the rails. Be sure the rails and carriage are in the positions shown in the assembly drawings.

6 Seat the bearings in the adapter.

7 Put the spacer on the shaft and push the shaft through the bearings. Fasten the snap ring.

8 Mount the adapter in the carriage, sliding the follower into the groove at the same time. Fasten the two screws.



Bench checking the unit

1 Check the unit assembly against the assembly drawing.

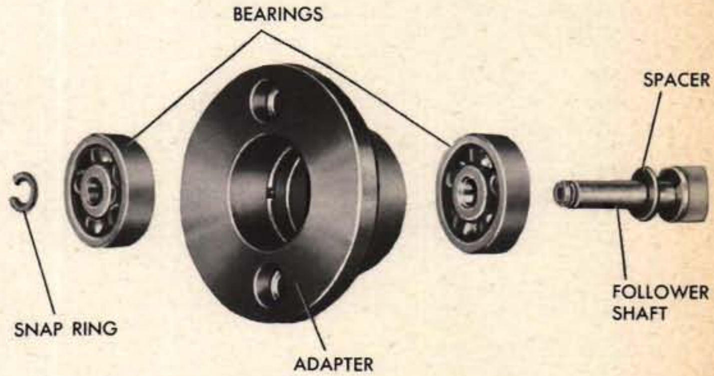
2 All gear teeth and bearings and the follower and groove must be properly lubricated.

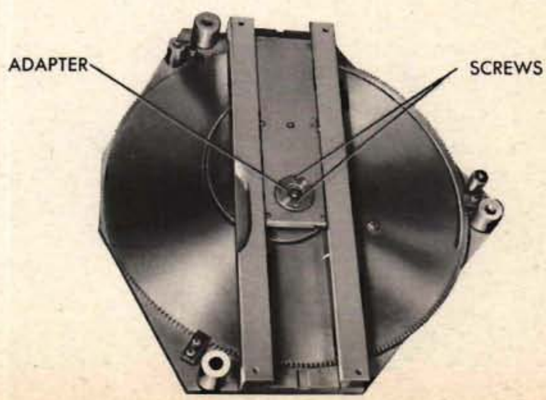
3 The cam should turn freely through its required limits of travel. Consult the assembly drawing for information about the travel limits.

4 The follower must move easily and there must be a minimum of lost motion between the follower and the cam groove.

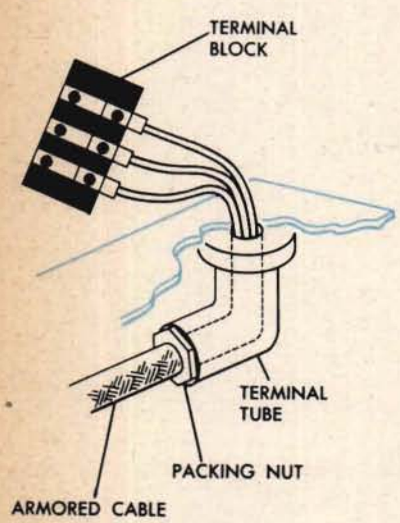
5 The carriage on the reciprocal cam must move freely and with minimum side play between the carriage and rails.

6 All gear meshes should be free and have a minimum of lost motion.





WIRING

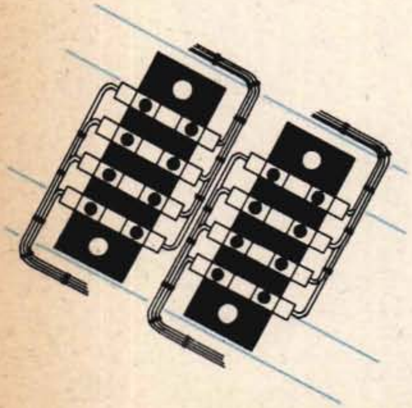


Ship's wiring

The ship's wiring is bound in armored or in rubber-sheathed cables. These cables enter the instrument through terminal tubes equipped with packing nuts and glands to make a water seal. Inside the instrument, the armor or sheathing is cut off flush with the terminal tube and the wires are led to terminal blocks. Each wire terminal is attached to a bus bar according to the designation number stamped on the block. For information on ship's wiring, refer to the ship's wiring diagram.

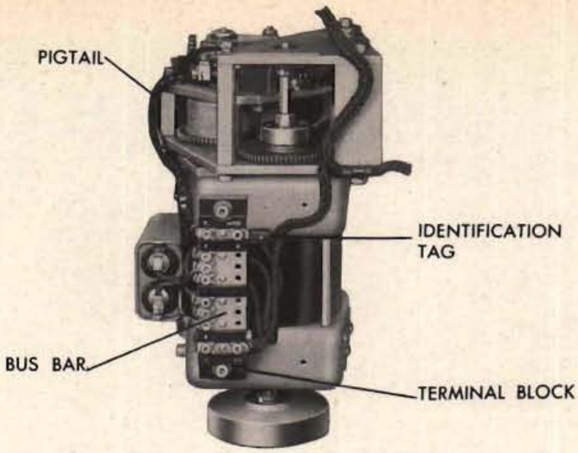
Instrument wiring

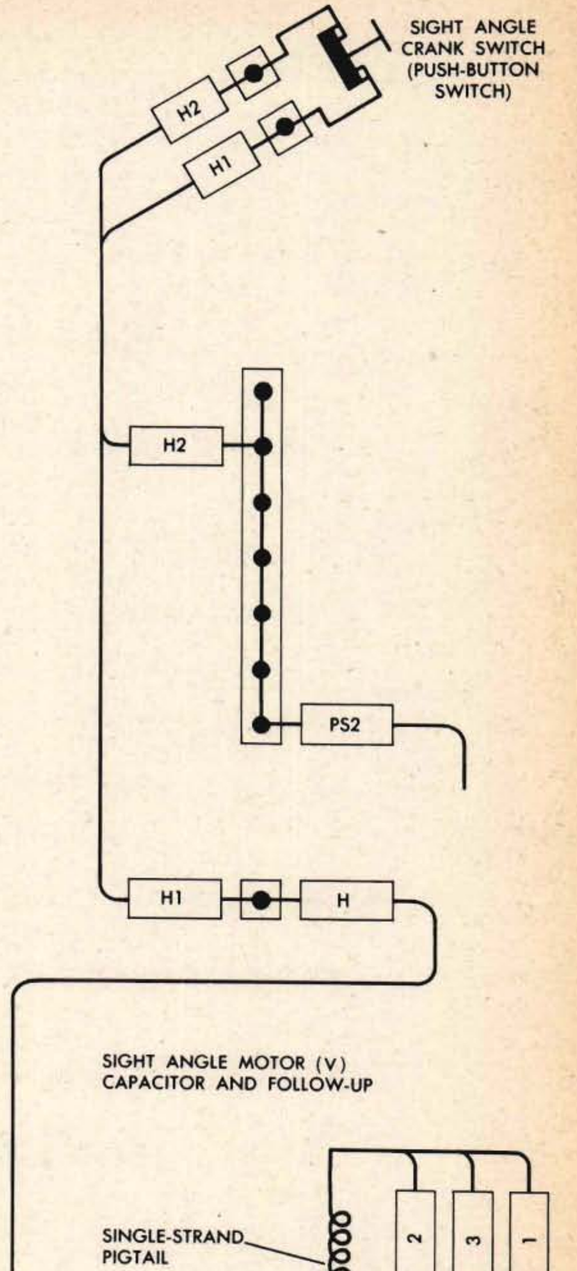
The instrument wiring leads from these blocks to individual units in the instrument. Usually, the instrument wiring is bound into cables which are led to intermediate terminal blocks in different sections of the instrument before single wires are led to the terminal blocks on the various electromechanical units.



Identifying wires

Letters are assigned to distinguish the different circuits. Numbers are added to the letters to distinguish the individual wires in the circuits, each wire having the same designation at both ends. In the instrument, these designations appear wherever a connection is made. They are stamped on the identification tags at the ends of the wires, on the terminal blocks, and on the units. These designations also appear on the instrument wiring diagrams, appropriately connected by lines. In order to facilitate reading, lines which have the same destination are merged to keep the number of lines at a minimum. Where lines cross each other, always go straight across, never turn to the left or to the right. The place where two lines merge or cross *does not* indicate a common connection. A common connection, which usually involves the use of a bus bar or a terminal post, is indicated by . A soldered connection, usually made inside a unit, is indicated by .

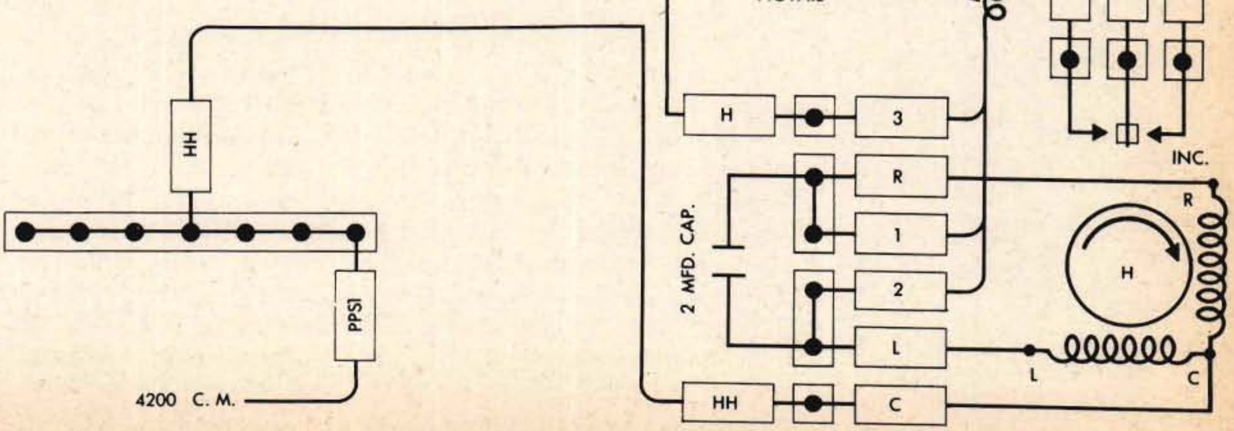


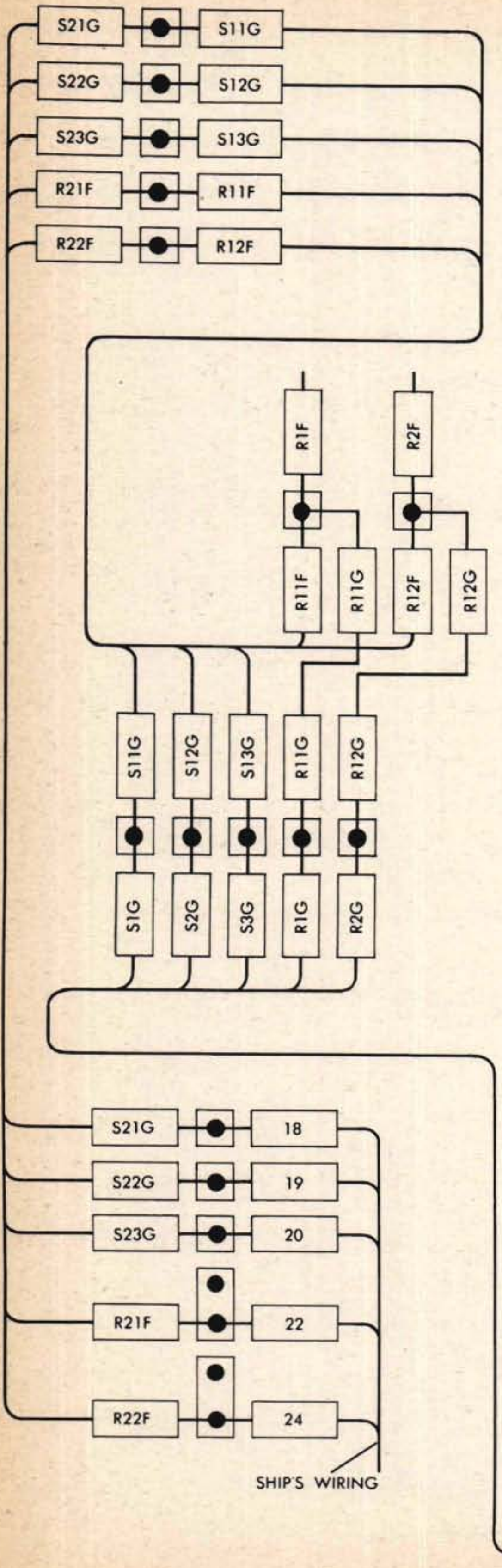


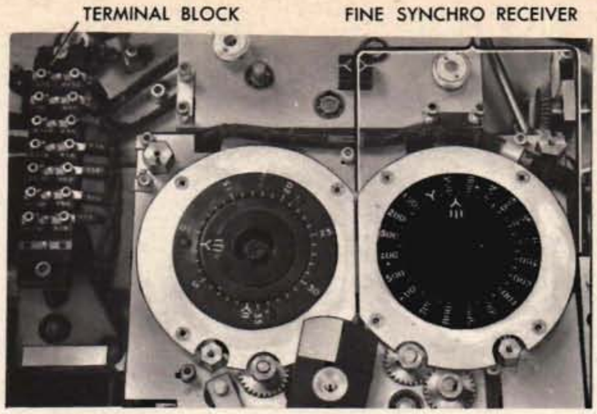
For servo motor circuits, each motor is assigned a letter (or a number and a letter), and the wires connected to the servo motor terminal block are assigned the same letter. For example, in the portion of the wiring diagram which appears on this page, H is the designation of the motor. The wire connected to the same bus bar on the motor terminal block as the pigtail wire leading to the center contact (3) is also designated H. The wire connected to the central stator lead (C) is designated HH.

In the single-letter circuit, one (1) is added after the letter for each additional wire between the motor and one of the power supply terminal blocks (PS2). The designations then become H1 for the first additional wire and H2 for the second additional wire.

In the double-letter circuit, there is only one wire between the motor and a power supply block (PPS1), but if there had been additional wires, they would have been numbered as in the single-letter (HH1, HH2, etc.).

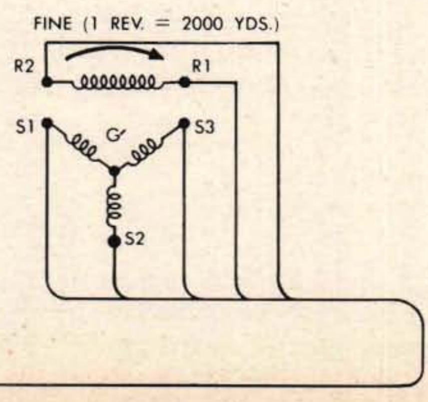






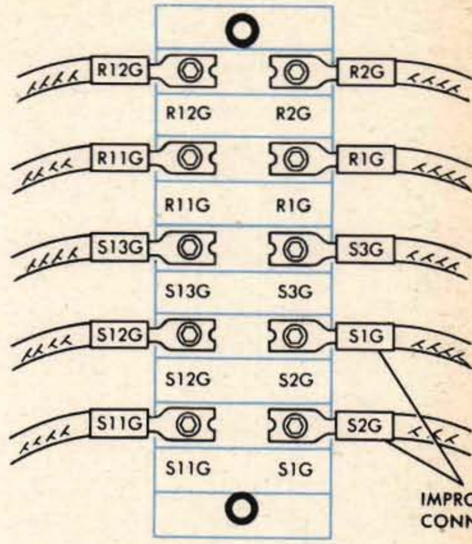
For synchro transmission circuits, one or two letters are assigned to each synchro. The individual wires are distinguished by the rotor and stator lead markings followed by this assigned letter. For example, in the portion of the wiring diagram shown here, the synchro motor is assigned the letter G. The stampings S1, S2, S3 (stator leads) and R1 and R2 (rotor leads) appear on the synchro itself to identify the leads. At the terminal block end, each of these lead designations is followed by the letter G which is assigned to the unit. Ten (10) is added to the number for each additional wire in the circuit. The designations then become S11G, S12G, etc. until the terminal block with the ship's wiring is reached. Note that in this particular case, the rotor leads of the G circuit are connected in common to the rotor leads of synchro unit F.

Besides identifying wires, the wiring diagram contains a wealth of additional information, such as: the switch position necessary to close a circuit; directions of increasing rotation; contact for increasing rotation; size and type of wire; and the names of units.



Trouble-shooting the instrument wiring

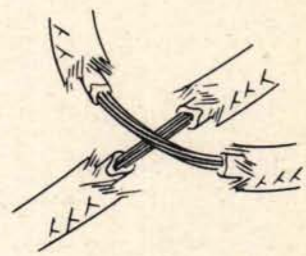
Trouble in the instrument wiring may be due to one of four causes: improper, short, open or grounded circuits. All the possibilities must be checked systematically, because there is no short-cut method of locating wiring trouble.



IMPROPER CONNECTION

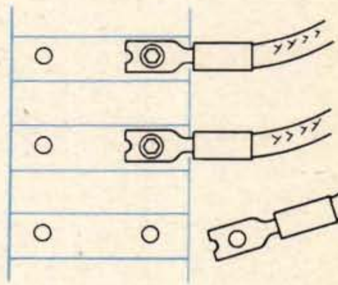
Improper connection

An improper connection occurs when a wire carrying current intended for one circuit energizes another circuit. An improper connection may be caused by a misplaced terminal on a bus bar, bare wires making contact, or a piece of foreign conducting material bridging two or more terminals.


SHORT CIRCUIT

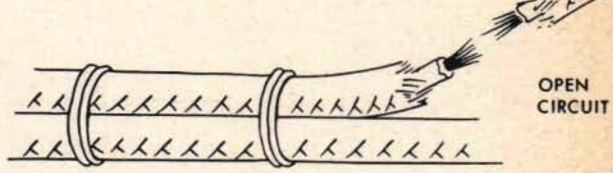
Short circuit

A short circuit occurs when the current is bypassed from one side of the supply to the other. Fuses of proper size should protect the equipment, but damage may result from the heat generated by the flow of excessive current through a short. A short circuit may be caused by crossed wires or an improper connection.


OPEN CIRCUIT

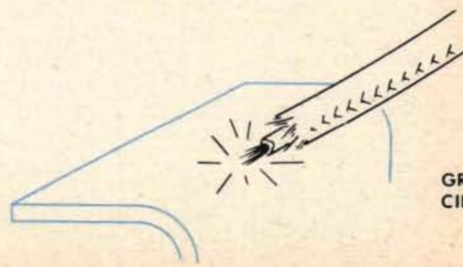
Open circuit

An open circuit is one having a break or gap. An open circuit may be caused by a loose or detached terminal, or by a broken wire.

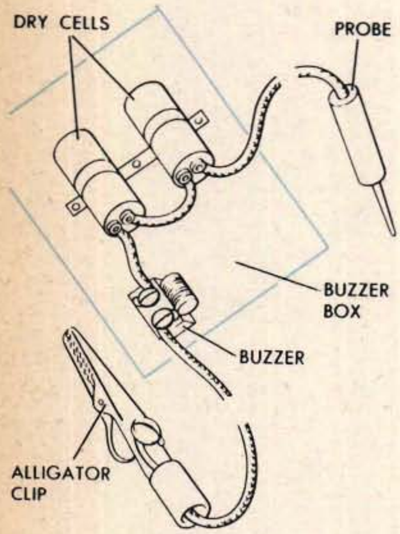

OPEN CIRCUIT

Grounded circuit

A wire is considered grounded if it touches the case or plates of an instrument. Damage occurs only when the grounded wire makes a circuit to the other side of the supply line.


GROUNDED CIRCUIT

Buzzing through a circuit



One of the instruments used for checking the continuity of a circuit is the "buzzer box." The power switch should be OFF when the buzzer is used.

1 Use the wiring diagram to locate both ends of the circuit to be tested. Check that the designations are correct.

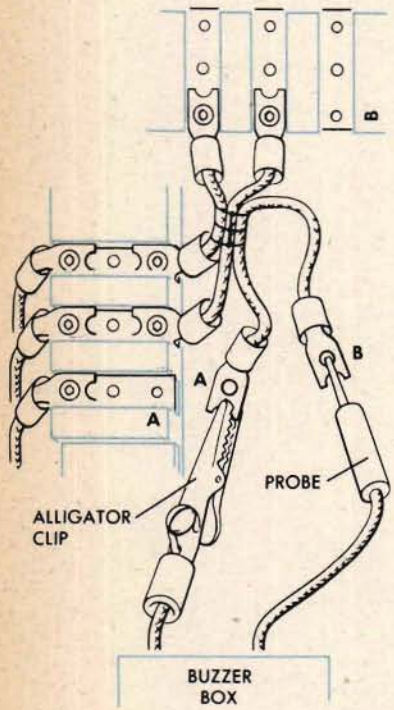
2 Position all switches and contacts in the circuit so that they close the circuit.

3 Disconnect the wires at the terminal blocks that energize the circuit.

4 Connect one of the leads from the buzzer box to one of these terminals.

5 Tap the other buzzer box lead to the other terminal. The buzzer will sound if the circuit is completed. A probe facilitates buzzing if there are no bare terminals. Use it to puncture the insulation and touch the wire.

Unless there is a resistor or a high-resistance winding in the circuit, a silent buzzer indicates that there is an open circuit. Use an ohmmeter to check a resistor or a high-resistance winding.



Locating the trouble

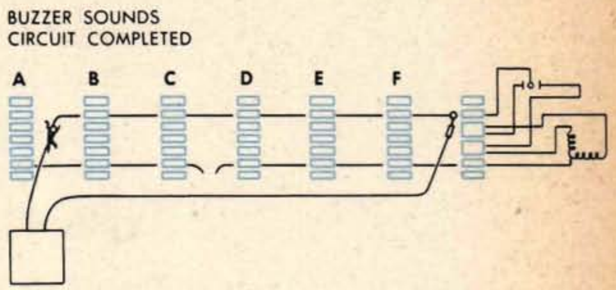
In short circuits and improper connections, tap one of the buzzer leads against the terminals of adjacent wires. Look for signs of melted copper and scorched insulation; these signs sometimes accompany shorts.

Sounding of the buzzer when one of the buzzer leads is tapped against the case of the instrument indicates that the circuit is grounded. The insulation resistance can be measured with a Megger as a further and more precise check.

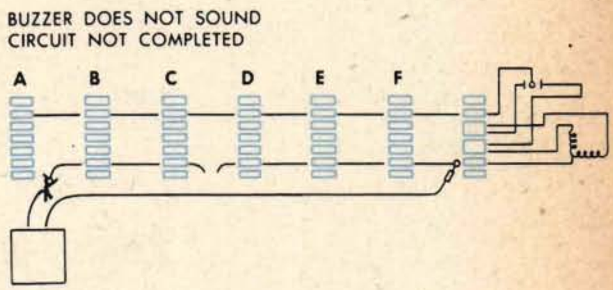
Isolate the source of trouble by a method similar to that for locating the break in an open circuit.

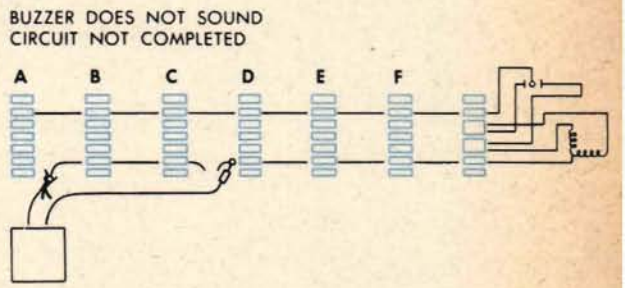
Locating the break in an open circuit

1 Test the portions of the circuit where the break is suspected. Sounding of the buzzer indicates a continuous circuit.

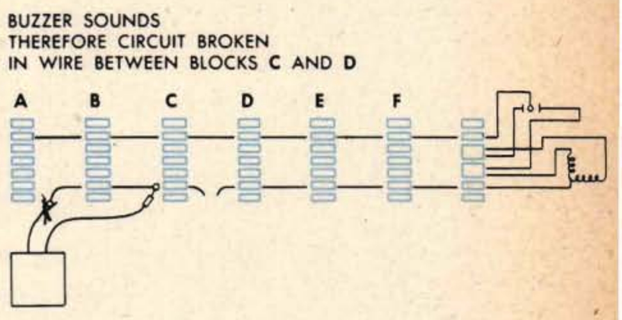


2 When the buzzer does not sound, the portion of the circuit with the break has been found.

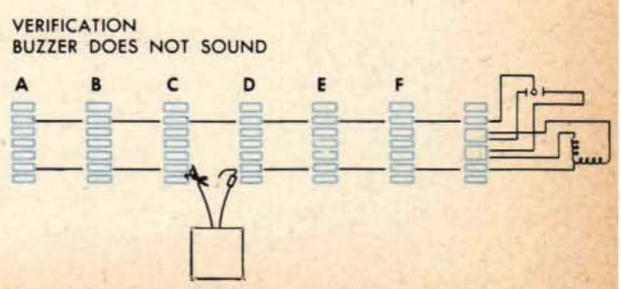




3 Narrow the broken portion down until the buzzer sounds.



4 Verify the location of the break, by making contact on the ends of the wire in question.



Repair procedure

When the source of wiring trouble has been located, make the necessary replacement, using the same size and kind of wire as used for the original connection.

Types of wire

Two sizes of stranded wire, made according to Navy Specifications, are used for instrument wiring. The size and type is noted on the wiring diagram. The lighter type is used between units and the heavier for power-supply circuits. In addition, pigtail wiring is used where great flexibility is required.

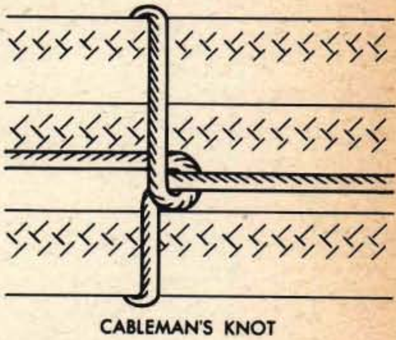
Replacing a wire

A broken wire or one with damaged insulation should be replaced. Whenever possible, replace only ONE wire at a time to avoid making an improper connection.

1. Remove wire terminals from the bus bars on the terminal blocks.
2. Clip the terminals from the old wire to remove the identification tags or sleeves.
3. Cut a new length of the same type of wire slightly longer than the piece to be replaced.
4. If possible, remove the damaged wire. If the wire cannot be removed, tape the ends. Where possible clip the lacing, bend the new wire so that it follows the same course as the old wire, and relace. Keep the wiring neat.
5. With the new wire in place, cut the ends to proper length by matching them to their bus bars on the terminal blocks.
6. Remove the insulation from the ends of the wire.
7. Slip the identification tags over the ends of the new wire.
8. Solder or crimp new terminals to the ends of the wire.
9. Clean the flat faces of the terminals.
10. Attach the terminals to the proper bus bars on the terminal blocks.

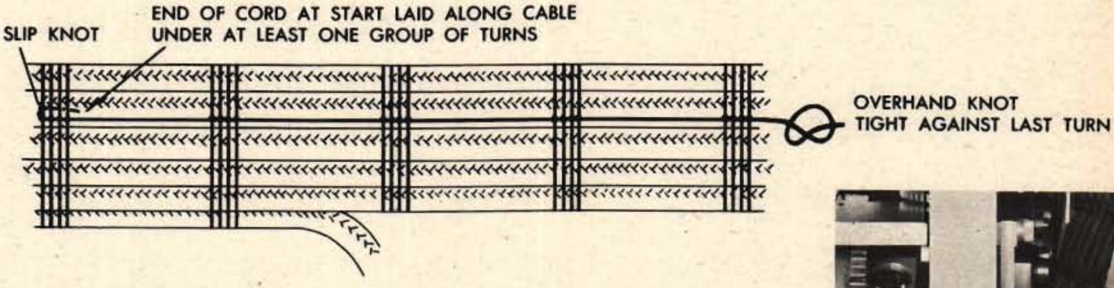
Binding a cable

Since individual wires are likely to sag and catch in adjacent mechanisms, they are always bound or laced together in a cable where two or more follow the same path. Waxed cotton cord is used for binding. Before binding is begun, all wires must be parallel. Apply the cord as shown in the accompanying sketch, using only the regulation cableman's knot. Draw each knot tight before proceeding to the next. The table shows the number of turns of cord to be used in each group and the spaces between groups in binding wires into a cable.

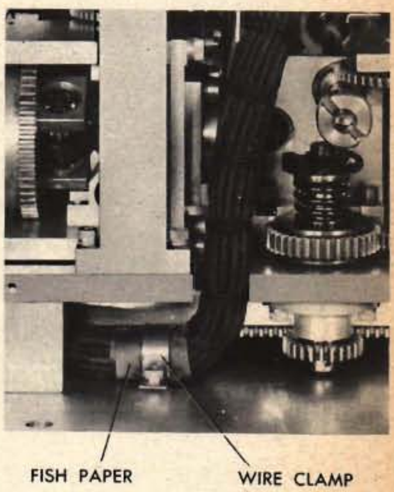


CABLEMAN'S KNOT

Number of wires	Number of turns	Spacing
from 2 to 4	1	1″
5 to 15	2	1″
16 to 25	3	¾″
26 to 35	4	¾″
36 to 75	5	¾″

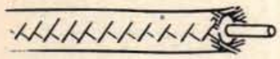


After binding a cable, secure it in place with wire clamps. Place fish paper, a tough insulating material, between the cable and the clamp, unless the wires are shielded. Use the clamps on shielded wire cables as intermediate grounds. In either case, the clamp should hold the cable firmly in place, but without cutting into the insulation.



Attaching soldered terminals

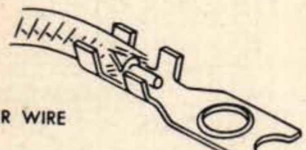
REMOVE INSULATION



1 Remove about ⅛ inch of insulation from the end of the wire, being careful not to cut or nick individual strands of the wire.

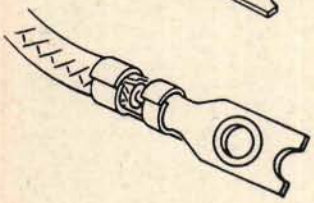
2 Using a rosin-type flux, tin the exposed end of the wire.

PLACE WIRE IN GROOVE



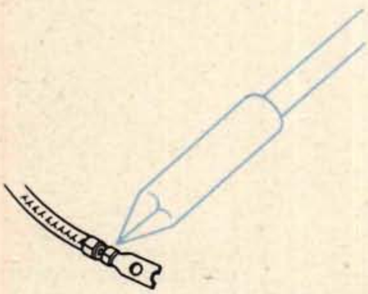
3 Place the tinned wire between the lugs of the terminal, with the longer lugs at the insulation and the shorter lugs at the bare wire.

FOLD LUGS OVER WIRE



4 Fold the long lugs tightly over the insulation and the short lugs over the wire.

SOLDER



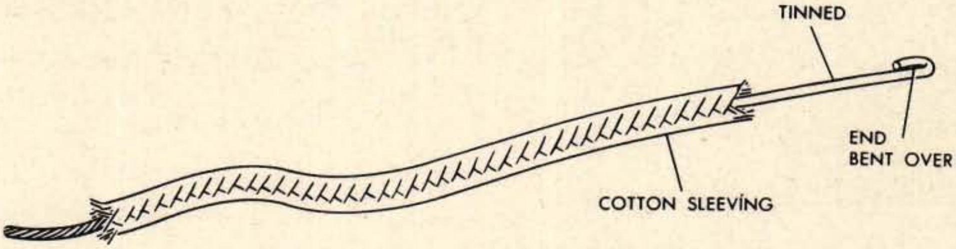
5 Heat the short lugs. Add a drop of solder.

6 Using a cloth dampened with alcohol, wipe excess flux from the surface.

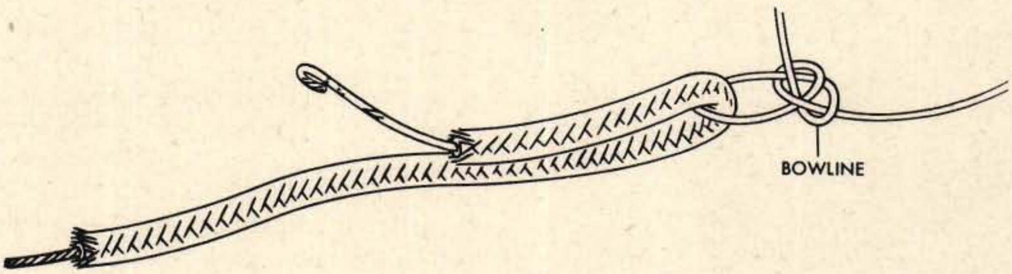
Repairing pigtail wiring

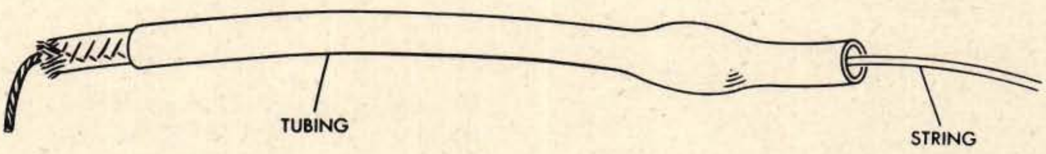
Pigtail wiring is used where great flexibility is desired. It consists of a lightly twisted strand of very fine copper wires threaded through cotton sleeving. Where pigtail wires are bound into a cable and clamped to the unit, no flexibility is required. The pigtails are then run through extruded plastic tubing to prevent shorts and grounds. Before repairs can be made, it may be necessary not only to cut the binding but to remove the entire pigtail cable. More skill is required to repair pigtail wiring than to repair ordinary wiring.

To thread a strand of pigtail wire through the cotton sleeving, tin the strand for two inches for stiffness, and bend the end over so that it will slip smoothly through the sleeving.



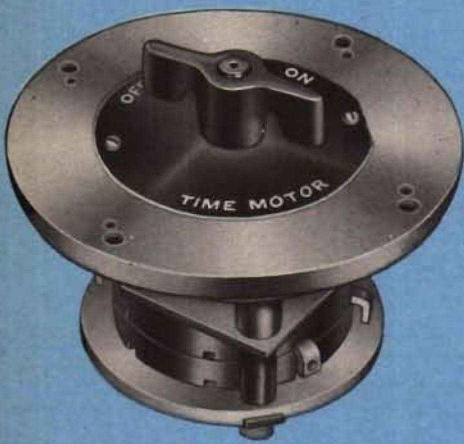
To thread the wire and the sleeving through the tubing, tie a bowline at one end of a string slightly longer than the tubing and pass the other end of the string through the tubing. Loop one end of the pigtail in the bowline. Pull the wire through the tubing.





In order to avoid burning or charring the cotton sleeving when soldering pigtail wiring, do not heat the iron any more than is necessary to do the job. Do not allow solder to run back along the thin wire, because it will make the wire stiff. Also, be very careful not to break any of the fine wires. Broken wires may pierce the cotton sleeving, become grounded, cause a short circuit and burn out the lead.

SWITCHES



A ROTARY SWITCH


A PUSH-BUTTON SWITCH

A LEAF-SPRING SWITCH

There are three main types of switches: rotary, push-button, and leaf-spring.

A rotary switch is operated by turning a handle attached to the shaft of the switch.

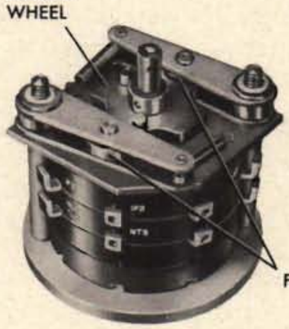
A push-button switch is usually located under a handcrank. When the handcrank is put in the IN position, the switch-actuating screw at the end of the shaft presses against the push-button and opens the circuit.

A leaf-spring switch is usually actuated by a push-button on the cover of the instrument. Pressing the push-button closes the circuit.

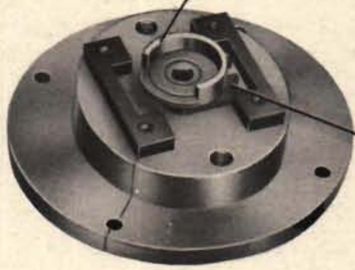
Any of these switches can be removed from the instrument by disconnecting the leads and taking out the mounting screws.

Rotary switches

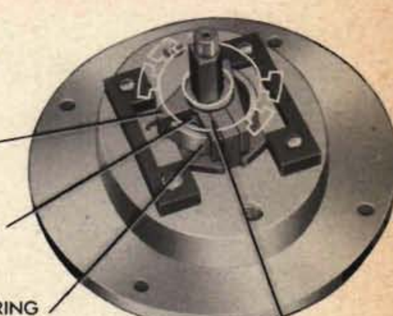
Two types of rotary switches are discussed in this chapter, the direct-action type and the delayed-action type.



DIRECT-ACTION TYPE
TOP PLATE REMOVED



DELAYED-ACTION TYPE
UNDERSIDE OF TOP PLATE



The direct-action type is controlled by a regular detent mechanism, which is like the detent described in the chapter on shaft line devices, page 124.

The delayed-action type is somewhat more complicated. This is how it works.

Turning the handle rotates the spring winder, which winds the strong coil spring against the spring support.

Simultaneously, the eccentric pulls the pawl, which is detained between the two bars, in toward the center.

The pawl acts as a trigger. When it clears the corner of a bar, the spring unwinds with a snap, and the spring support, the rotor, and the pawl jump one quarter of a turn to a new position.

The almost instantaneous opening of circuits that results from the snapping action of this switch minimizes arcing. For this reason, the POWER switch usually is a delayed-action type of switch.

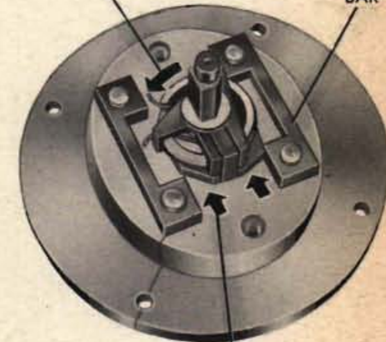
If a switch does not operate properly, look for one of the following symptoms:

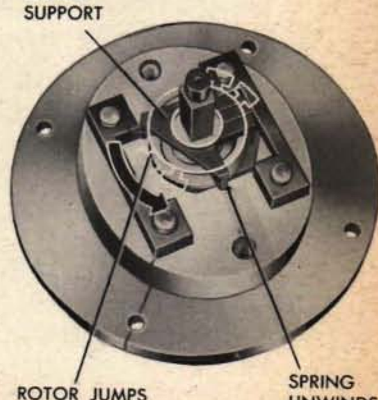
JAMMING: The handle or the push-button cannot be moved.

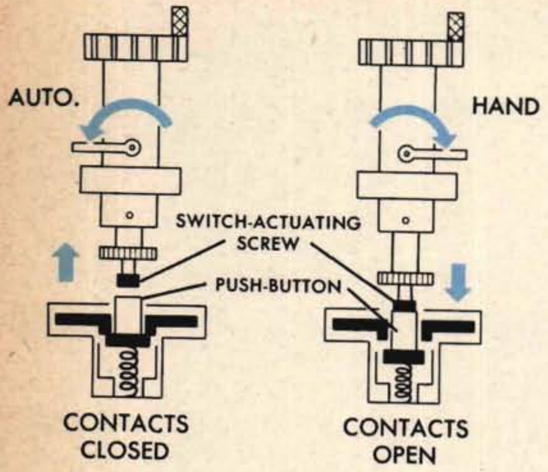
STICKING: The handle or the push-button operates with difficulty.

SLIPPING: In a rotary switch, there is no feeling of detent action when the handle is turned.

ELECTRICAL TROUBLE: The contacts fail to close the circuit when they are brought together.



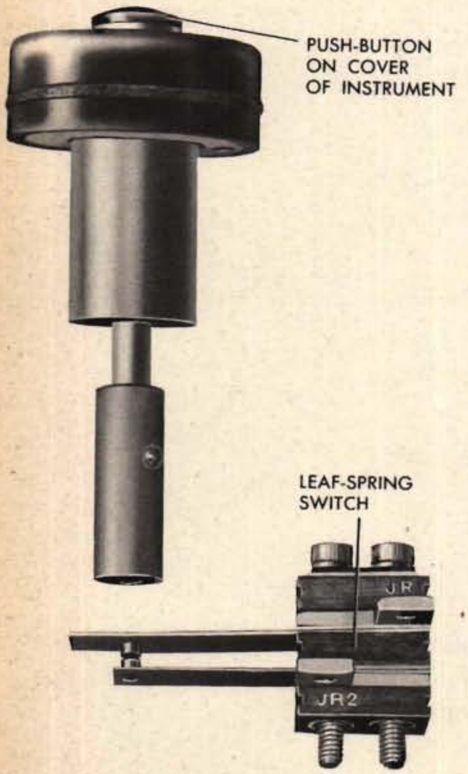




Locating the cause

In locating the cause of trouble in a push-button switch, first check the setting of the handcrank switch-actuating screw that depresses the button.

In locating the cause of trouble in a leaf-spring switch, first check the operation of the push-button that presses the contacts together.

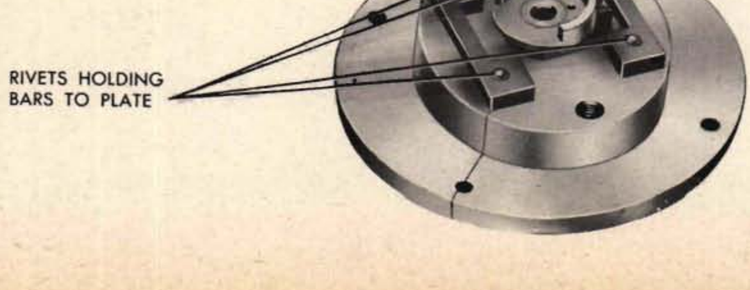


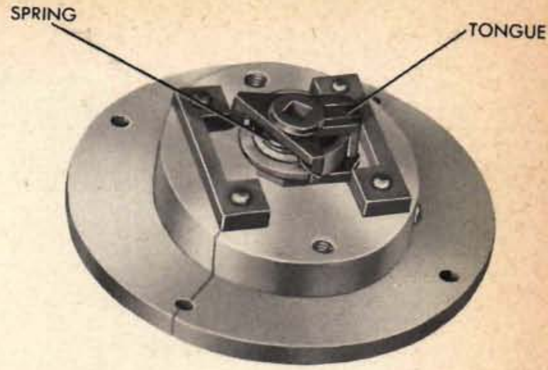
Jamming or sticking

In either type of rotary switch, jamming or sticking may be caused by a dirty or damaged bearing on the shaft which supports the rotor, or by bent contacts. Also, if one of the screws which hold the switch together is loose, the bakelite sections may tilt and permit the rotor contacts to jam against the terminal contacts inside the switch.

A casualty in the detent of a direct-action type may result in jamming or sticking.

In the delayed-action type, the rivets holding the bars to the plate may become loose, permitting the pawl to jam against the bar, or a dirty or damaged eccentric may jam or stick in the pawl.



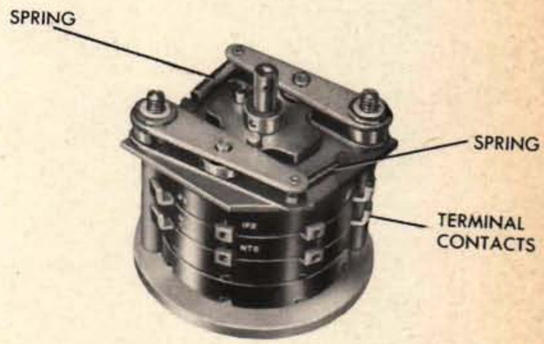


DELAYED-ACTION
ROTARY SWITCH

Slipping

In the delayed-action type, a broken spring or a broken tongue on the spring support may not only prevent the switch from snapping to a new position when the handle is turned, but may prevent it from staying in any one position.

Likewise, in the direct-action type, if a spring on one of the follower arms becomes unhooked or damaged, the detent probably will not operate properly; the handle will turn freely, but the detent will not hold the rotor in position.



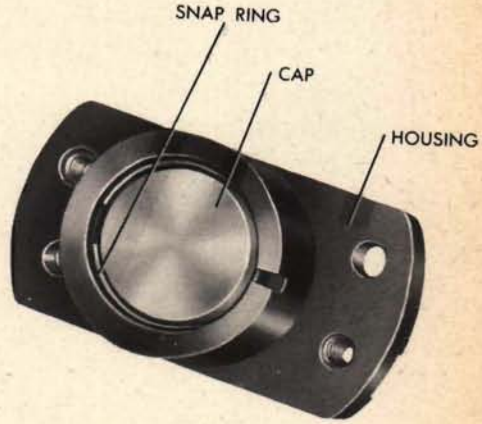
DIRECT-ACTION
ROTARY SWITCH

Electrical trouble

Dirty, damaged, or broken contacts may cause electrical failure in any of the switches.

In the push-button switch, the button may be pushed down so far by the switch-actuating screw on the handcrank that the cap, spring, and button are forced out of the housing.

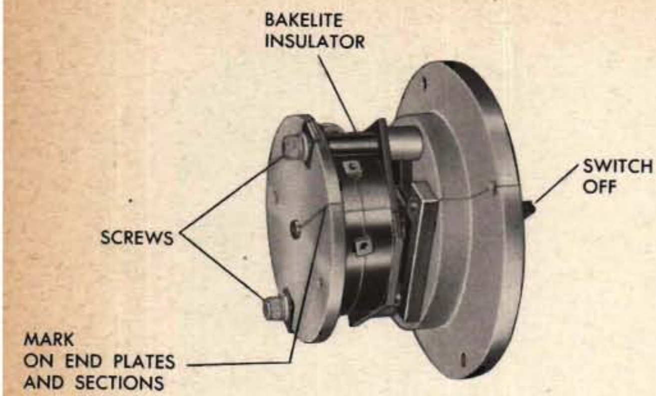
To locate the cause of electrical trouble in a switch, refer to the wiring diagram to trace the circuits. Use a buzzer, or a similar device, to test the circuits and locate the contacts which have failed.



PUSH-BUTTON SWITCH
(BOTTOM VIEW)

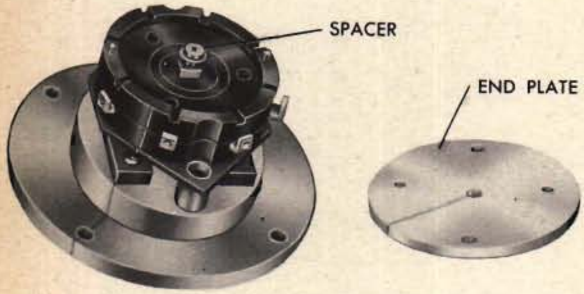
Disassembling switches

In preparing to disassemble any switch, disconnect the leads and remove the screws that hold the switch in the instrument. It may be necessary also to remove the handle, the handle adapter, or other mechanical connection.



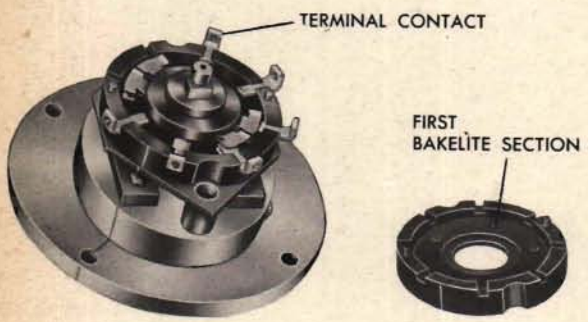
Disassembling the rotary switch

The disassembly procedure is practically the same for either type of rotary switch. The instructions that follow cover the delayed-action type, which is slightly more complex than the direct-action type.



1 Set the switch handle at the OFF position and mark the relationship between the end plates and the bakelite sections, as illustrated.

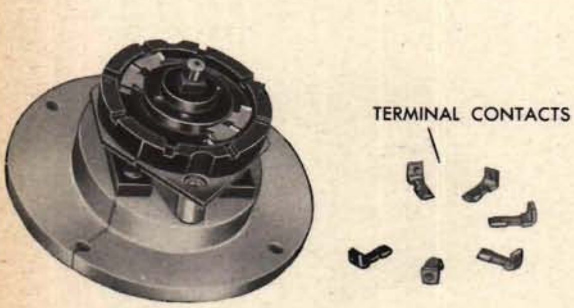
2 Remove the two long screws holding the switch together. (The two bakelite insulators will fall off.)



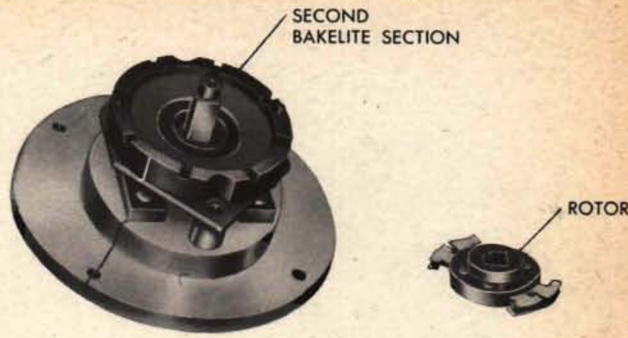
3 Remove the end plate from the switch and the spacer from its shaft. Tag the spacer.

4 Lift off the first bakelite section.

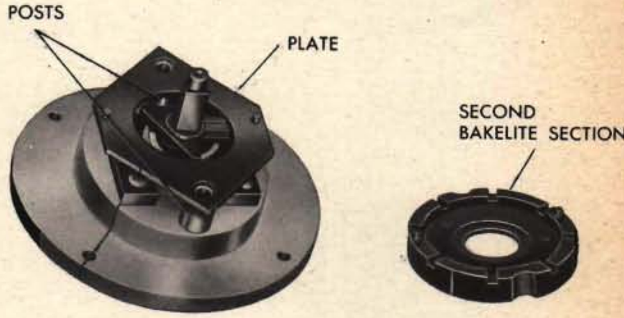
5 Remove the terminal contacts. As an aid to correct reassembly, make a sketch to show the relationship of the terminal contacts to the mark made in step 1.



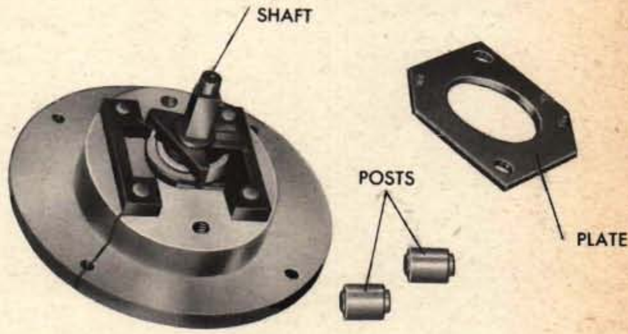
6 Remove the rotor.



7 Remove the second bakelite section.

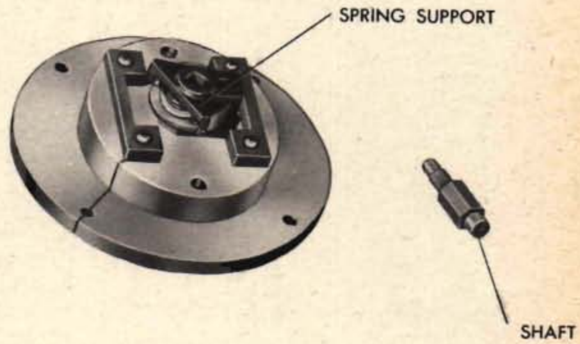


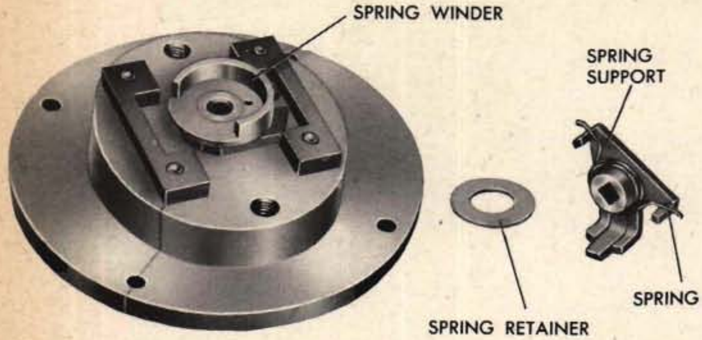
8 Lift off the metal plate.



9 Remove the two posts from the housing.

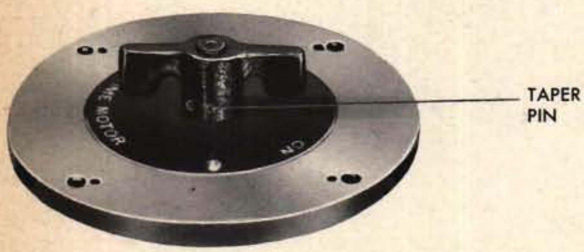
10 Lift out the shaft.



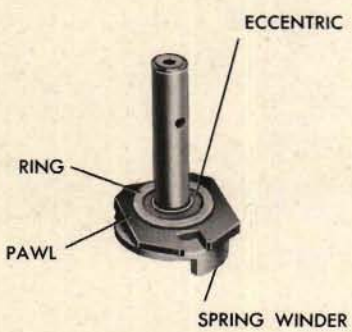


11 Remove the spring support and spring. Separate the spring from the support.

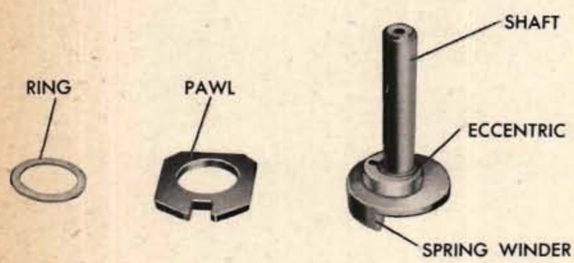
12 Pick up the spring retainer in the spring winder.



13 Drive the taper pin out of the handle and take the handle off its shaft.



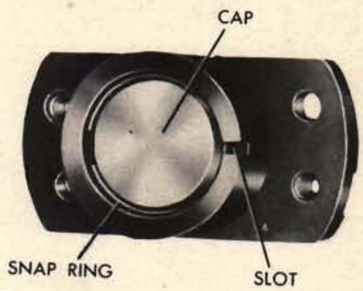
14 Pull the spring-winder assembly out of the front plate.



15 Supporting the spring winder on the pawl, drive the ring off the eccentric by tapping on the shaft.

Disassembling the push-button switch

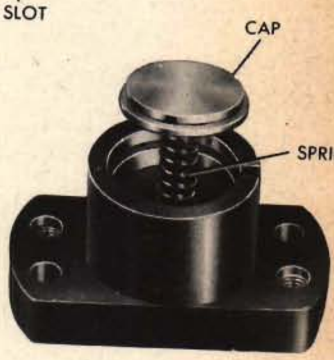
1 Remove the insulating spacer from the housing.



2 Take out the snap ring by pressing the cap down and inserting a tool in the slot of the housing.

3 Remove the cap and the coil spring.

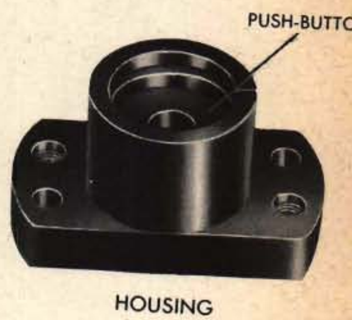
4 Lift out the push-button.



Repairing the parts

All switches

Replace a spring or any part that has been broken.



The rotary switch

Clean dirty contact surfaces with an approved solvent. Polish pitted contact surfaces with a fine abrasive paper or a fine oil stone.

Lubricate (with an approved lubricant) the terminal contacts after they have been cleaned.

Straighten a bent shaft according to the instructions in *Basic Repair Operations,* page 69.

Clean and polish a shaft that binds in a plate.

Clean dirty ball bearings with an approved solvent. Replace damaged bearings.

Rerivet a loose bar in the delayed-action switch. Position it according to the assembly drawing.

In the multiple switch, stone a burred detent wheel.

The push-button switch

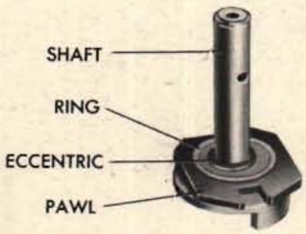
If the housing or a contact is damaged, replace the entire switch.

Reassembling switches

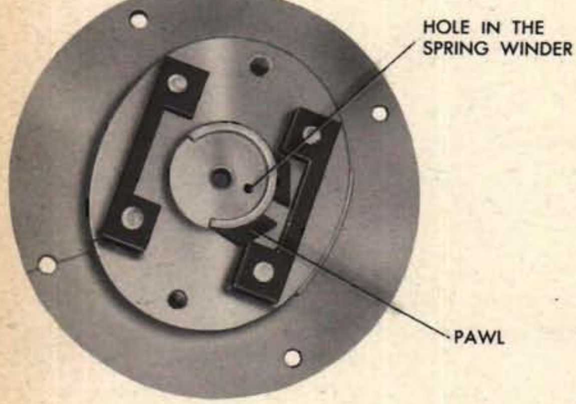
Wash all the parts with an approved solvent and dry them before reassembly. Use an approved lubricant on all the moving parts.

Refer to the assembly drawing for guidance in the reassembly procedure.

Reassembling the rotary switch



1 Place the pawl over the eccentric, and the ring over the pawl. Stake the ring and check that the pawl turns freely on the eccentric.

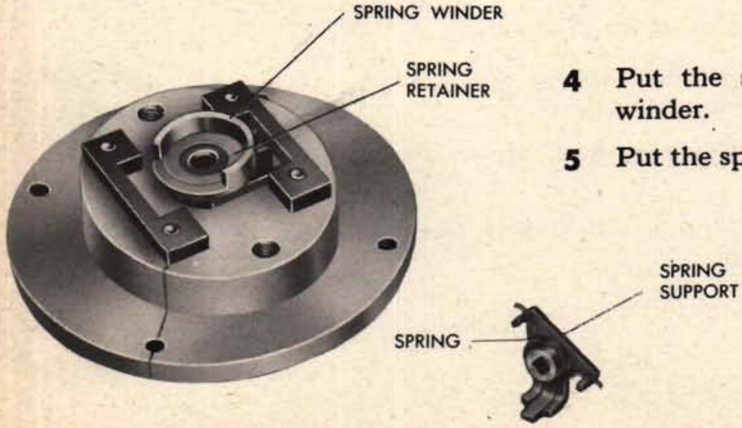


2 Put the shaft through the front plate.

3 Pin the handle to the shaft.

NOTE.

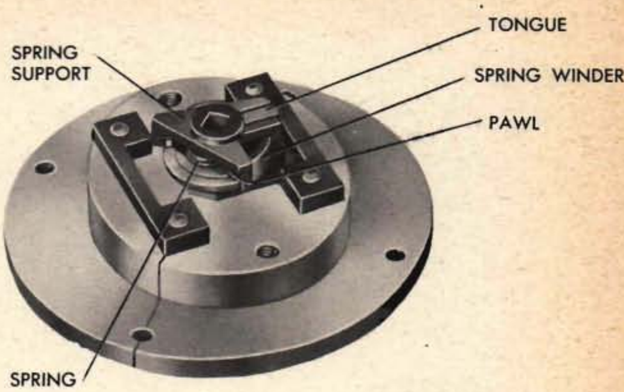
In the steps which follow, keep the hole in the spring winder over the slot in the pawl.



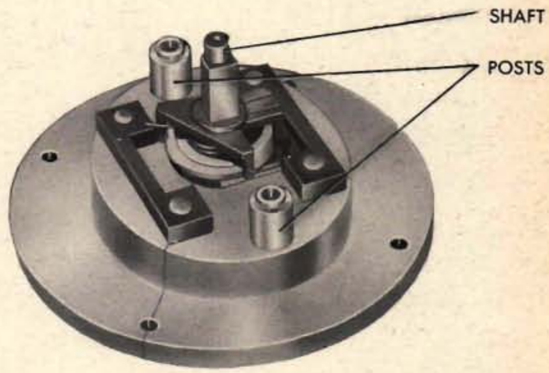
4 Put the spring retainer in the spring winder.

5 Put the spring in the spring support.

6 Mount the spring support on the spring winder. The tongue of the support fits into the slot in the pawl.

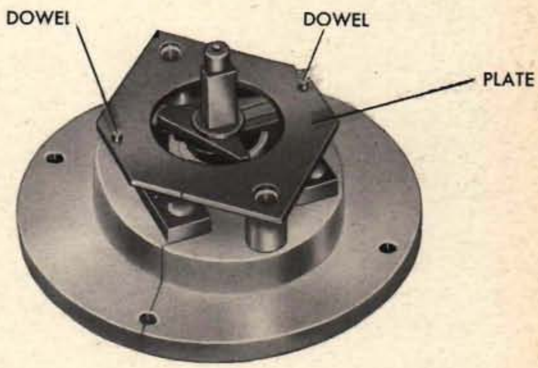


7 Place the square end of the shaft in the hole of the spring support.

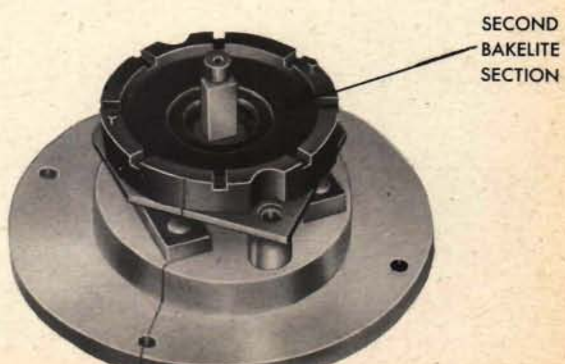


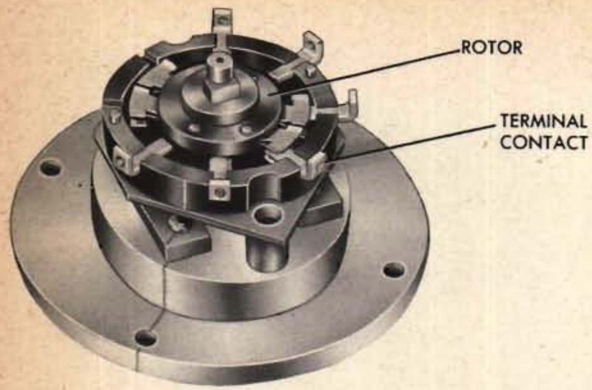
8 Mount the posts with their small shoulders down.

9 Mount the plate on the posts with the dowels up, aligning the mark on it with the mark on the front plate.



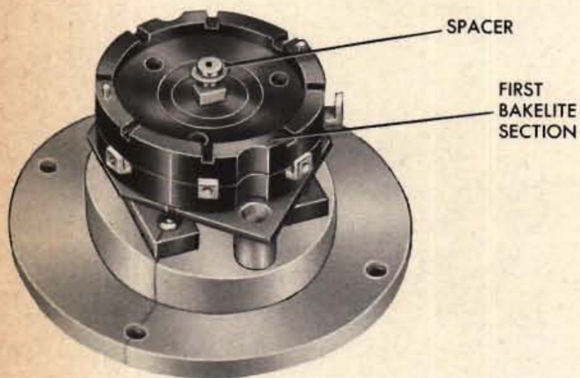
10 Mount the second bakelite section.





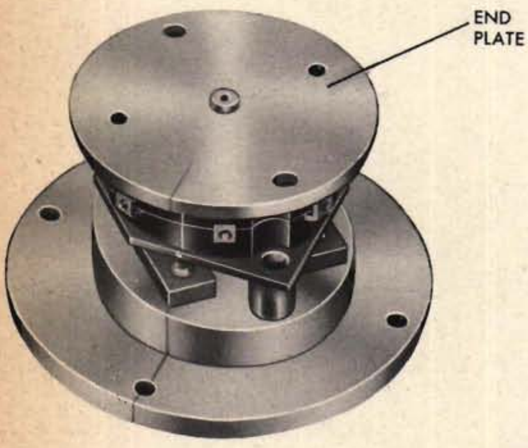
11 Mount the rotor.

12 Put the terminal contacts in place. Lubricate them lightly with an approved lubricant.

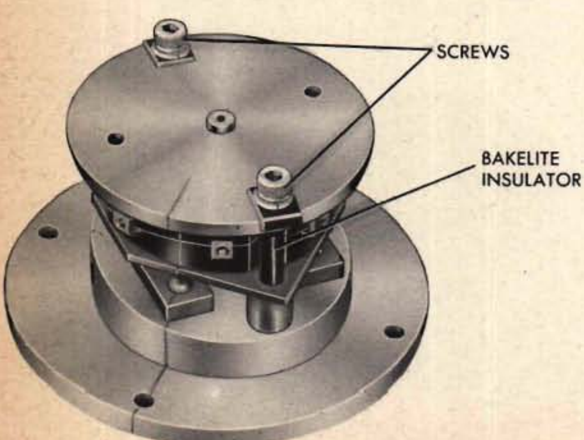


13 Mount the first bakelite section.

14 Place the spacer on the shaft.



15 Mount the end plate.

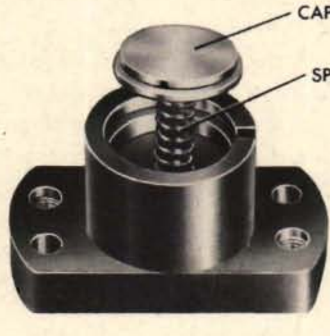


16 Hold the bakelite insulators between the plates and fasten the assembly together with the two long screws.

Reassembling the push-button switch

1 Put the push-button in the housing.

2 Insert the coil spring with the cap on top of it.



3 Put the snap ring in place.

4 Put the insulating spacer in place.

Bench checking the unit

All switches

Check for continuity. The contacts must open and close properly when the switch is operated.

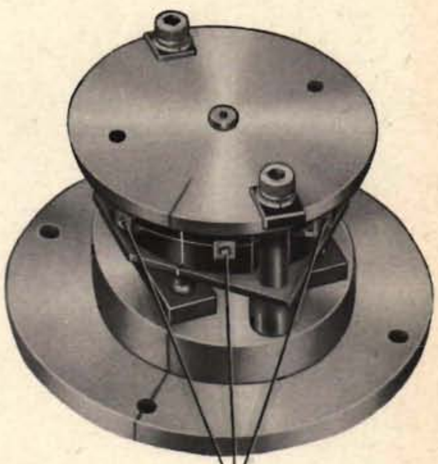
Rotary switches

1 Check the switch with the assembly drawing and the instrument wiring diagram.

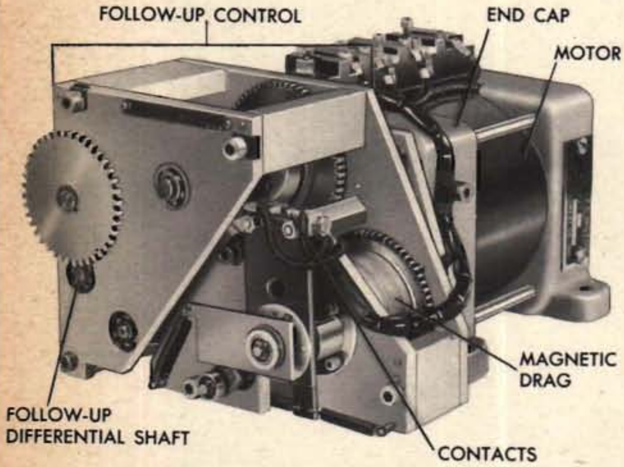
2 The switch must operate freely, but with positive detent action.

3 The threads in the terminal contacts should be checked for damage. (They usually are tapped for No. 6-32 machine screws.)

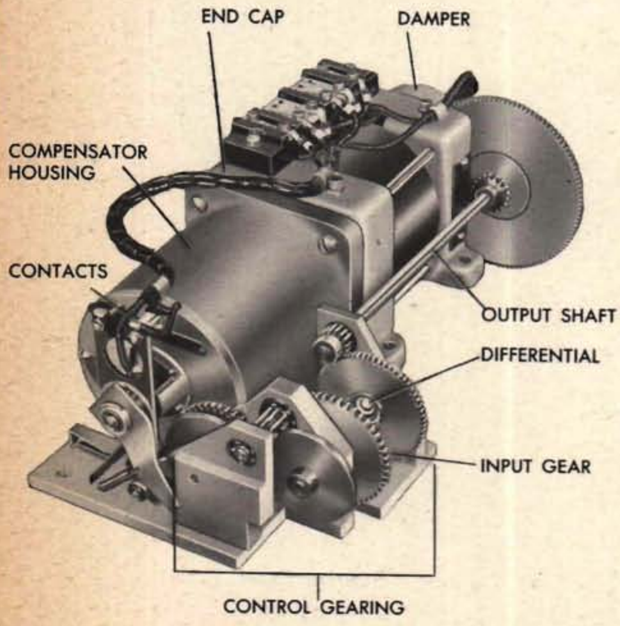
4 The handle position must agree with the circuits connected.



THE FOLLOW-UP



A MAGNETIC DRAG FOLLOW-UP



A COMPENSATED FOLLOW-UP

The types of follow-ups described in this chapter are electromechanical devices for amplifying the motion and power of shaft lines. They consist of a follow-up control, a motor, the wiring connecting the control with the motor, and a capacitor connected with the motor. In addition, a damper is usually provided.

In all the controls covered in this chapter, the contacts are actuated by intermittent gearing driven by the output of a differential. This differential, called the follow-up differential, compares the input with the response from the output of the follow-up.

The name of a follow-up is usually derived from some conspicuous feature in the design of the follow-up control.

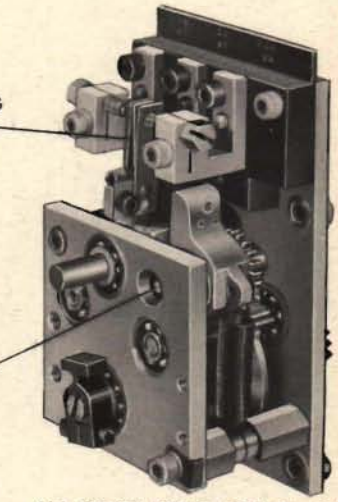
The MAGNETIC DRAG FOLLOW-UP, sometimes called the velocity-lag type, features a magnetic drag in the control. The entire control, consisting of the differential, the output gearing, the intermittent gearing, the contacts, and the magnetic drag, is contained in a framework mounted directly on one end cap of the motor. The follow-up can be removed from the instrument as one unit.

The COMPENSATED FOLLOW-UP, sometimes called the acceleration-lag follow-up, features a compensator which is enclosed in a housing attached to one end cap of the motor. The contacts are mounted on the compensator housing. The control gearing, consisting of the differential, the motor output gearing, and the intermittent gearing are mounted separately on a plate.

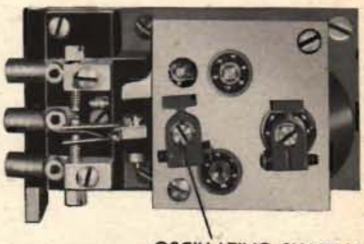
The OSCILLATING FOLLOW-UP features oscillating center contacts. The component parts of an oscillating follow-up are separated in the instrument. The control unit, consisting of the intermittent gearing, the contacts, the signal cam and the eccentric shaft which causes the center contacts to oscillate, is contained in a gear box which can be removed easily as one unit. The differential, motor, and control unit are connected by shaft lines. The contacts in this follow-up control are oscillated to reduce contact "dead space." In some forms of this follow-up, the oscillating feature is omitted or locked.

All these follow-ups, while different in construction, can develop the same general troubles because they operate on similar principles.

Some minor repair work may be done on follow-ups while they are mounted in the instrument. Because foreign matter may fall into other units if repairs are made in place, always cover the adjacent units well. If it is necessary to remove a follow-up from the instrument, consult the instrument instruction book.



AN OSCILLATING FOLLOW-UP CONTROL UNIT



A FOLLOW-UP CONTROL UNIT WITH OSCILLATING FEATURE LOCKED

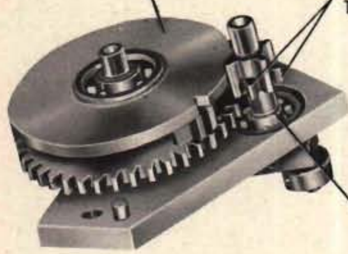
Typical symptoms

If tests indicate that a follow-up is not operating properly, even though 115-volt 60-cycle A.C. is brought to the terminal block, look for one of the following typical symptoms:

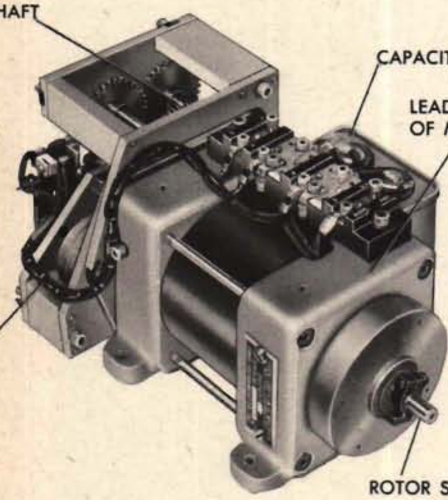
Failure to run
Running away
Slipping
Rough output
Sluggishness
Excessive oscillation

Locating the cause

Failure to run



OUTER PLATE, COMPENSATED FOLLOW-UP CONTROL GEARING



Failure of a follow-up to run may be due to a mechanical or an electrical cause.

Jammed gearing may prevent the follow-up from operating. If only the output shaft line is jammed, the input gearing, including the intermittent gearing, will be free to turn, and vice versa. If neither the input nor the output shaft line is free to turn, probably the differential spider is jammed. Locate the source of trouble by using the methods in the chapter *Shaft Lines,* page 92.

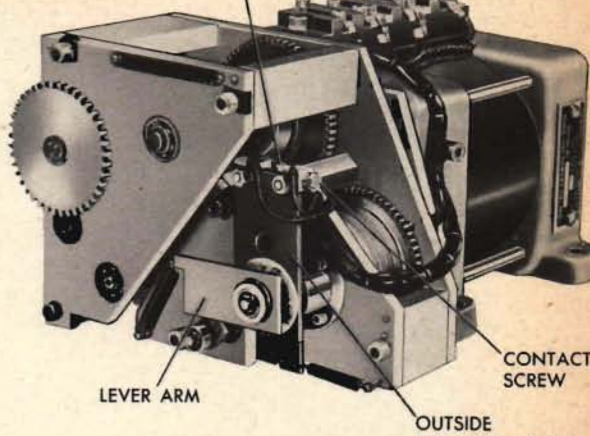
A locking disk may jam on the ends of cutaway teeth of an intermittent pinion if spacers were improperly replaced at reassembly.

Electrical failure may be the result of an open connection, such as a break in the wiring, dirty contact surfaces, a faulty capacitor, or a common connection between L and R.

With the power ON, try turning the rotor. If it is absolutely free to turn, the trouble probably is an open circuit. Turn the power OFF and disconnect the incoming, *single-letter* lead. Turn the power ON and touch this lead to the bus bar marked L (or 2) in order to by-pass the contacts. This should cause the motor to run counterclockwise (viewed from the lead end). Shifting the lead to the bus bar marked R (or 1) should cause the motor to run clockwise.

CAUTION:
Do not allow the single-letter lead to touch the double-letter bus bar (also marked C). This would be a short circuit, and damage might result.

If the motor runs after the contacts are by-passed, probably the open is in the pigtail wiring leading to the contacts. If the motor is still stalled after the contacts are by-passed, there may be an open between the terminal block and the motor windings, or in the motor windings themselves. If the motor runs, but slowly, after being given a start, probably the capacitor is faulty. Turn the power OFF and replace the capacitor with a new one. Turn the power ON again and recheck the rotor torque.



If the rotor slightly resists turning, probably L and R are connected in common. This is often caused by the contact gap being closed completely.

Runaway follow-up

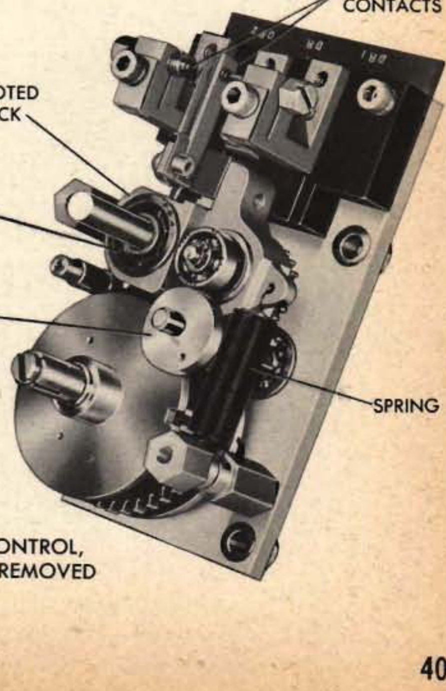
A follow-up running continuously in one direction, or until it runs into its limit stop, indicates a constant connection between the center and one of the outside contacts. This may be caused by improperly connected wires between the contacts and the terminal block in any type of follow-up.

In the magnetic drag and compensated follow-up controls, a constant connection between the center and one of the outside contacts may occur because of a jammed plain bearing between the lever arm and outside contact arm, which prevents the coil relief spring from returning the outside contact arm to its normal position with respect to the lever arm. The outside contact arm is in the normal position when the pins are together.

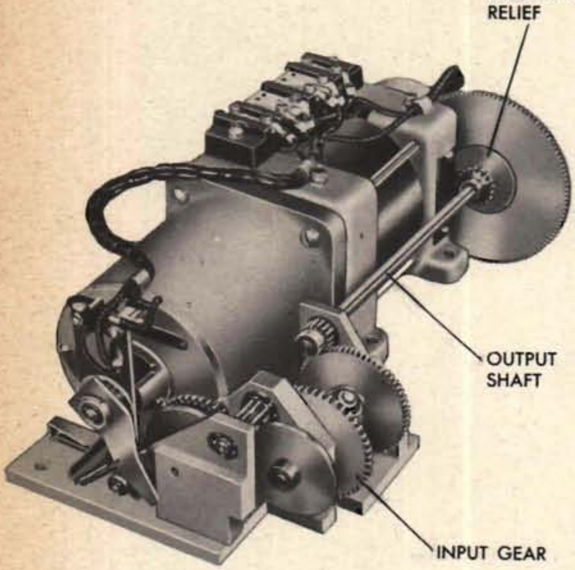
A constant connection also may occur if the pigtails are entangled, pulling the contacts over in one direction; if one of the centering springs is unhooked, broken or stretched, permitting the other spring to pull the center contact over; or if the center contact has been bent out of shape.

Casualties to the securely mounted outside contacts in the oscillating follow-up are infrequent. However, if the bearing for the pivoted block is sticky, or if the spring holding the pivoted block against the signal cam is stretched or damaged, the center contacts may bear against one of the outside contacts continuously, causing the follow-up to "run away."

OUTSIDE CONTACT-ARM ASSEMBLY, MAGNETIC DRAG FOLLOW-UP



OSCILLATING FOLLOW-UP CONTROL, FRONT PLATE REMOVED



Slipping

A follow-up is said to be slipping if the motor runs but the output shaft does not turn in exact proportion to the input shaft. Examine the shaft lines for sheared or missing taper pins and for loose clamps. Locate the source of slipping by the methods described on page 103.

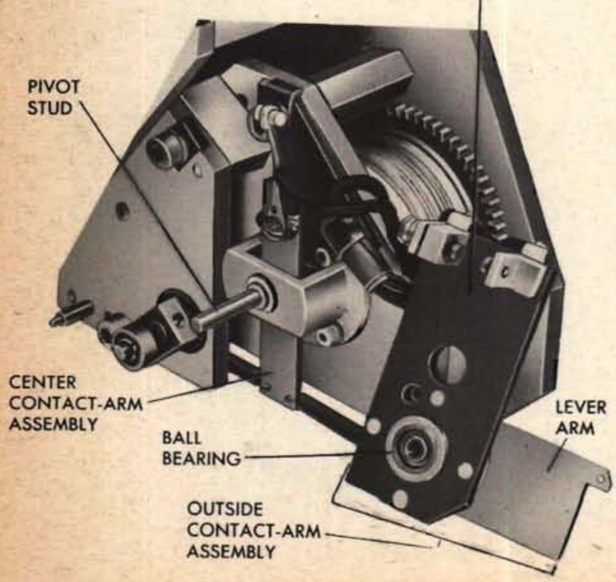
Slipping of a different nature results from a loose friction relief. Looseness of a friction affects the torque available for turning the output shaft line. The output may turn slowly or not at all even though the motor rotor turns. If the output turns at all, the follow-up will synchronize eventually, and the values of the input and output shafts will agree. Instructions for adjusting a friction relief are given on page 436. Data for setting friction torque are given on the follow-up assembly drawing.

Rough output

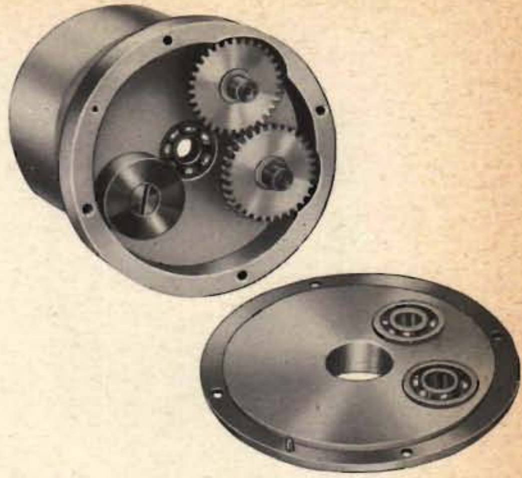
Roughness of the follow-up output is usually caused by sticky gearing or sticky contact-arm mountings. Roughness also may be caused by contacts which are dirty, pitted or poorly aligned.

A sticky input shaft line or contact-arm mounting has a more adverse effect on follow-up behavior than a sticky output shaft line. In order to locate stickiness, inspect the shaft lines as recommended on page 102.

Dirt in the gear meshes or bearings may often be washed out with an approved solvent without disassembly. However, if cleaning operations are conducted within the instrument, every precaution must be taken to avoid washing particles out of one unit into another.

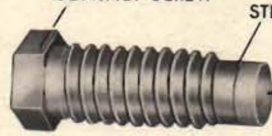


In either the magnetic drag or compensated follow-up control, a sticky magnetic-drag rotor will cause the center contact to move erratically.



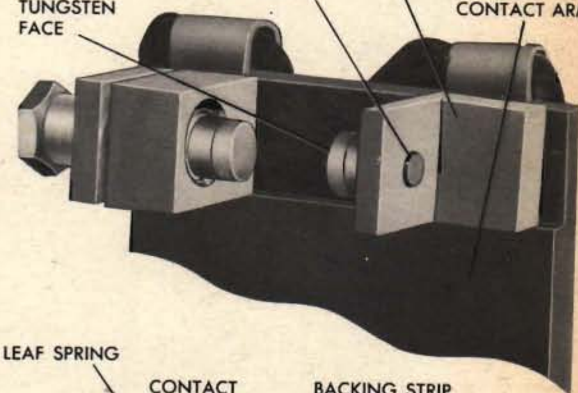
A COMPENSATOR, DISASSEMBLED

In the compensated follow-up, almost imperceptible amounts of foreign matter or dirt in the gear meshes or bearings inside the compensator can cause the center contact-arm assembly, and therefore the follow-up output, to move erratically.

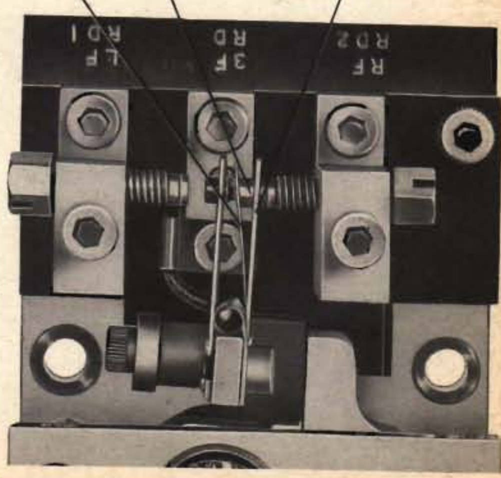


Sluggishness

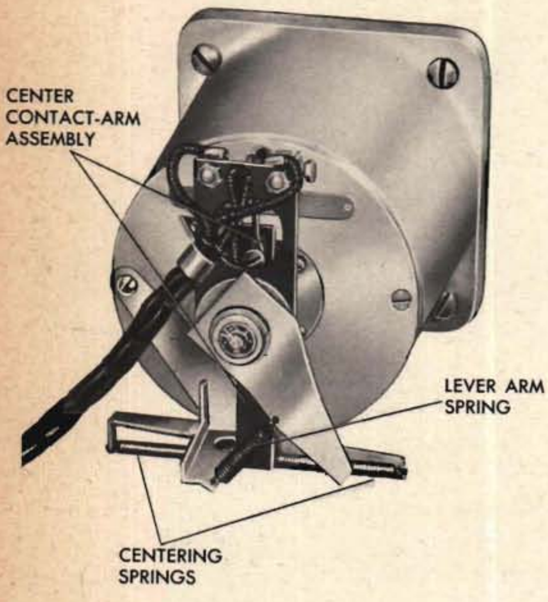
Slowness of a follow-up responding to a signal may indicate high resistance between the contact surfaces, or weak contact pressure.



Sluggishness resulting from high resistance between the contact surfaces may be caused by dirty, pitted, oxidized or broken contacts. In order to locate these troubles, examine the contacts closely. See that the contacts are clean and polished. Be sure that the tungsten face has not been broken off the steel shank. Check that the shank is firmly seated in the aluminum contact screw or contact post. Pitting and fouling will take place in a loose joint which may increase the resistance of the circuit enough to cause sluggishness.



In the oscillating unit, poor connection may result if a contact which is riveted to a leaf spring cocks in the backing-strip hole.

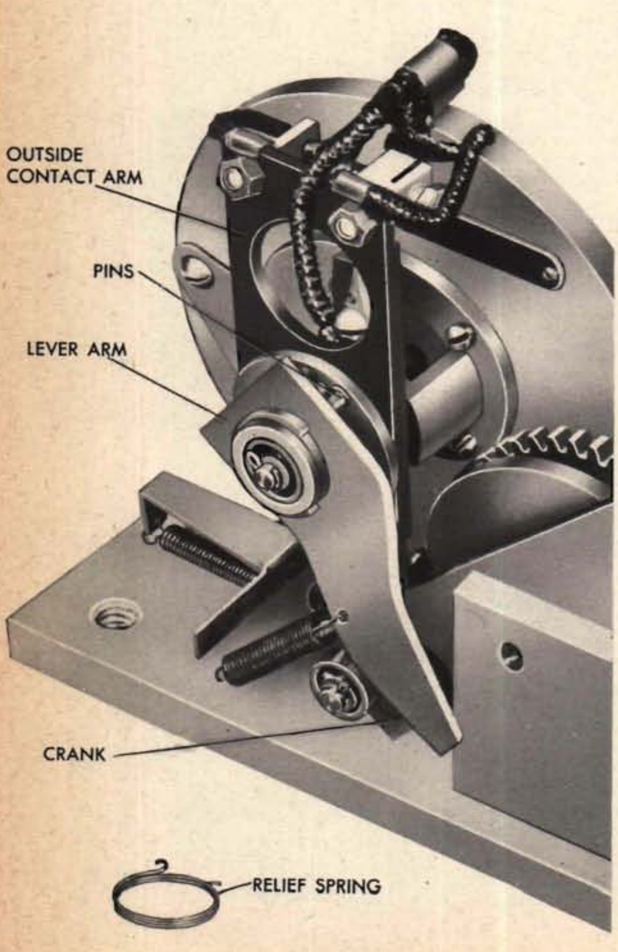


Sluggish operation due to weak contact pressure in the magnetic drag and compensated follow-ups may be caused by damaged centering springs, damage to the relief spring which is wound around the lever-arm sleeve, dirty and sticky plain bearing between the lever arm and outside contact arm, or damage to the lever arm spring.

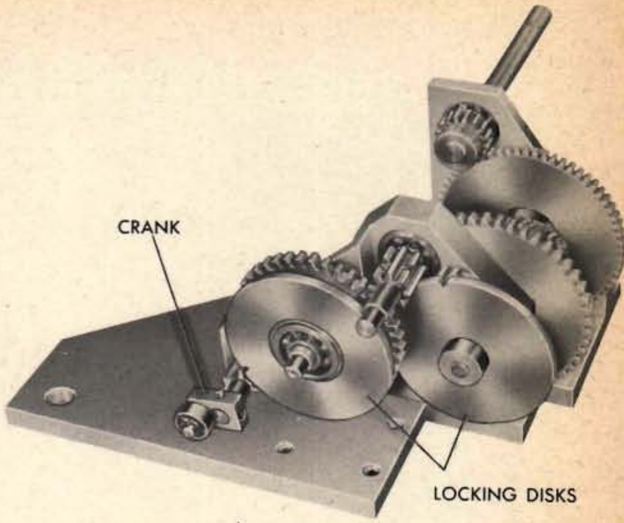
In order to detect trouble with the centering springs, observe the position of the center contact-arm assembly. It should stand at right angles to the centering springs when the contacts are in the synchronized position (center contact touching neither one of the outside contacts). If it is leaning to one side, probably one of the centering springs is weak.

In order to detect trouble in the outside contact-arm assembly, watch the manner in which it acts as the crank goes through the synchronized position (crank parallel to the lever arm). When the crank is moved up, the lever arm should turn with respect to the outside contact arm. This separates the two pins, winding up the relief spring which limits its contact pressure. When the crank is moved to the down position, the relief spring should return the arms to their original relationship, with the pins touching. If the arms do not return, either the plain bearing is sticky or the spring is weak. Remove the outside contact-arm assembly and separate the arms in order to determine whether the plain bearing or the spring is the cause of the trouble. If the plain bearing is sticky, repair it as directed on page 417. If the spring is damaged, replace it. Sometimes sluggishness due to a weakened relief spring can be alleviated temporarily by shortening one of the loops at the ends of the spring. If this is done, be sure to leave enough spring so that the arms can be turned with respect to each other to separate the pins by at least 3/16 inch.

If the follow-up runs slowly, even though the arms do return and the contacts are in good condition, probably the spring hooked to the lever arm is weak.



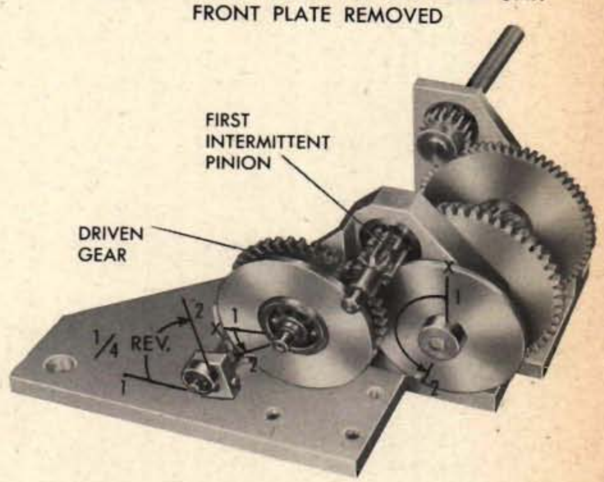
Another cause of sluggishness resulting from weak contact pressure is an incorrect relationship between the two locking disks. Watch the operation of the crank or cam, as the case may be. It should move in steps of 1/4 revolution. Movement in steps of 1/8 revolution indicates that the mesh between the first intermittent pinion and the gear it drives is incorrect by one tooth. This condition can result only from incorrect reassembly. For the correct reassembly procedure, refer to "Reassembling the control unit" of the follow-up in question.



COMPENSATED FOLLOW-UP CONTROL UNIT
FRONT PLATE REMOVED

Excessive oscillation

Excessive oscillation of a follow-up usually is caused by a casualty to one of the damping devices.

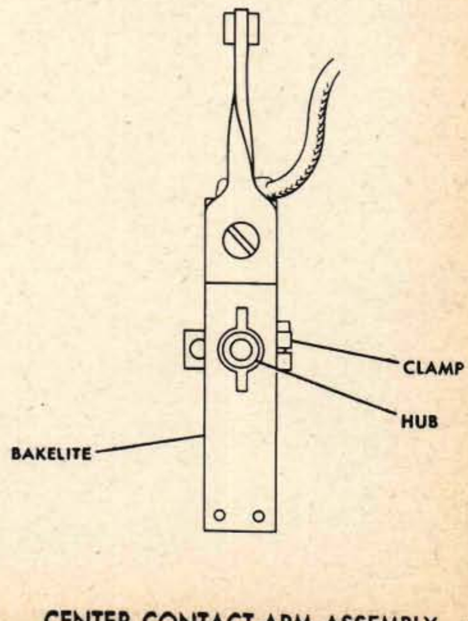


"Jiggling," or low-amplitude oscillation, may occur if the motor damper or the magnetic drag does not exert the normal amount of torque.

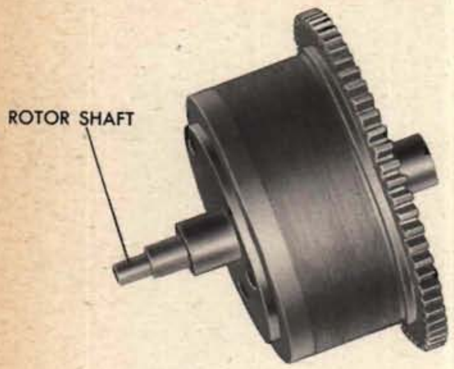
In the magnetic drag and compensated follow-ups, loosened riveting between the bakelite piece of the center contact-arm assembly and the split hub, or a loose clamp on the hub may prevent full application of available torque to the center contact arm.

Similarly, a weakened magnetic damper, an incorrectly adjusted mechanical damper, or a damper loosely clamped to the motor shaft, will decrease the damping action in all follow-ups.

A properly adjusted oscillating follow-up has a perceptible "jiggle." Do not attempt to eliminate this normal condition.

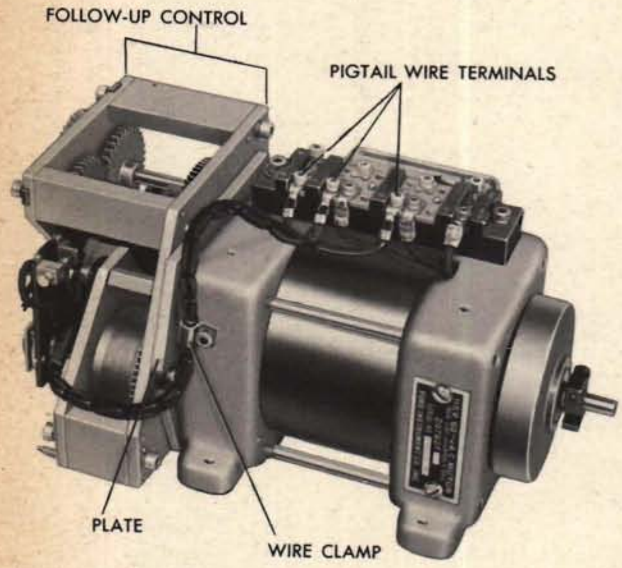


CENTER CONTACT-ARM ASSEMBLY



"Hunting," or large-amplitude oscillation, may occur in any follow-up if a damper rotor and case are locked together. In magnetic drag or compensated follow-ups, a sticky magnetic-drag rotor, or reversed left and right-hand leads (L and R) may cause hunting. When the L and R leads are reversed, the follow-up tries to synchronize with the crank arm pointing away from, instead of toward, the spring on the lever arm.

If trouble with a damper is suspected, refer to *Dampers*, page 440. Magnetic drags are similar to magnetic dampers in principle and construction; therefore, *Dampers* may also be used as a guide for trouble-shooting and repairing magnetic drags.

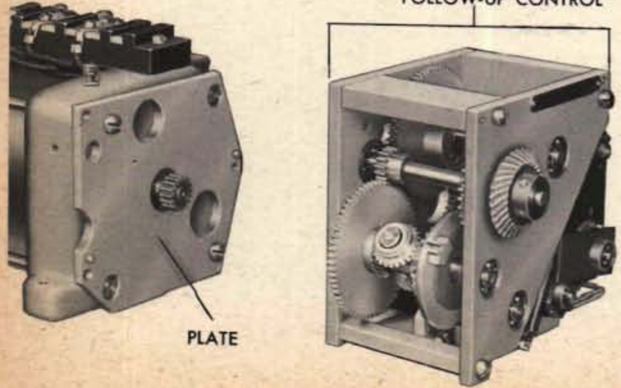


Disassembly

Before disassembling any follow-up, be sure the power supply is disconnected. Tag all spacers so that the parts may be reassembled in the proper relationship to each other.

Disassembly: Magnetic drag follow-up

The entire follow-up can be removed from the instrument as one unit.



Removing the control unit

(Usually the control unit need not be removed in order to disassemble it.)

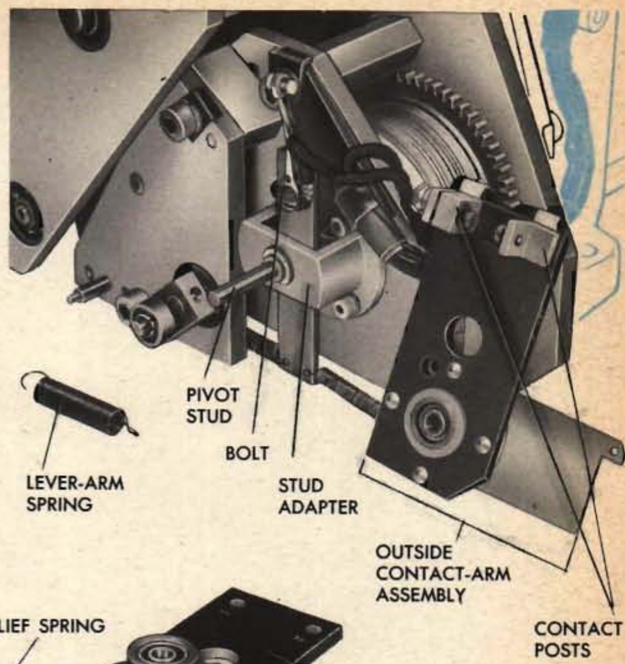
1 Detach the pigtail wires from the terminal block. Remove the wire clamp.

2 Remove the three screws, and pull the control unit off the plate attached to the motor.

3 Remove the plate attached to the motor. (Note the position of the plate with respect to the motor end cap.)

Removing the contacts

(The contacts can be removed while the control unit is attached to the motor.)



1 Unhook the lever-arm spring, pull the cotter pin out of the pivot stud and pull the outside contact-arm assembly off the stud. (Be careful not to stretch or damage the pigtail wiring.)

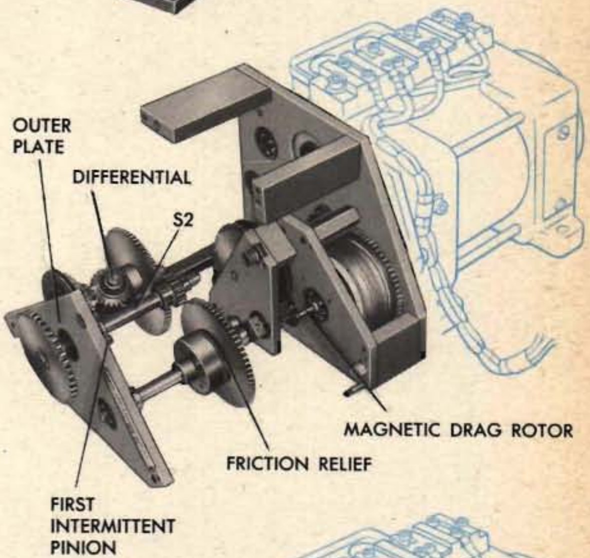
2 Remove the contact posts and the pigtail wiring. Tag the terminals.

3 Remove the snap ring and separate the two arms.

4 Unhook the centering springs and loosen the assembly clamp which holds the center contact arm to the magnetic drag rotor.

5 Take out the screws securing the stud adapter; remove the adapter and the center contact-arm assembly simultaneously.

6 Remove the bolt which holds the pigtail terminal and center contact arm to the bakelite piece and take off the contact arm.

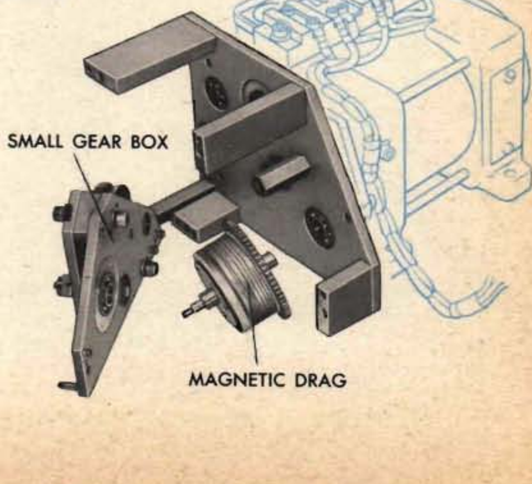


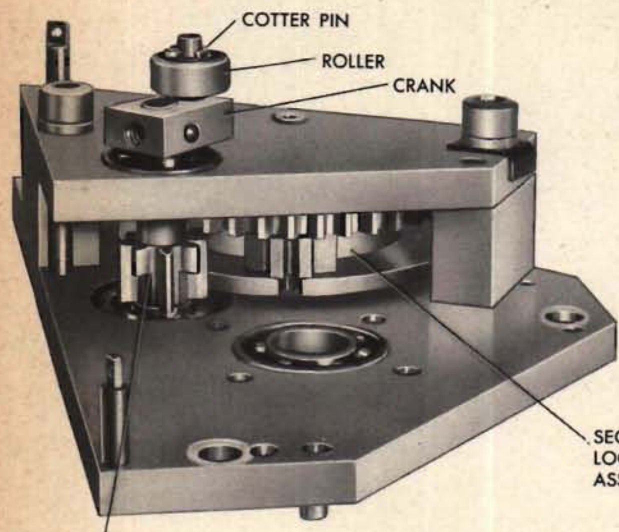
Disassembling the control unit

(The control unit can be disassembled without removing it from the motor.)

1 Take out the screws holding the outer plate; remove the plate together with the differential, friction relief, shaft (S2), and the first intermittent pinion.

2 Remove the small gear box containing the second intermittent pinion. Remove the magnetic drag.





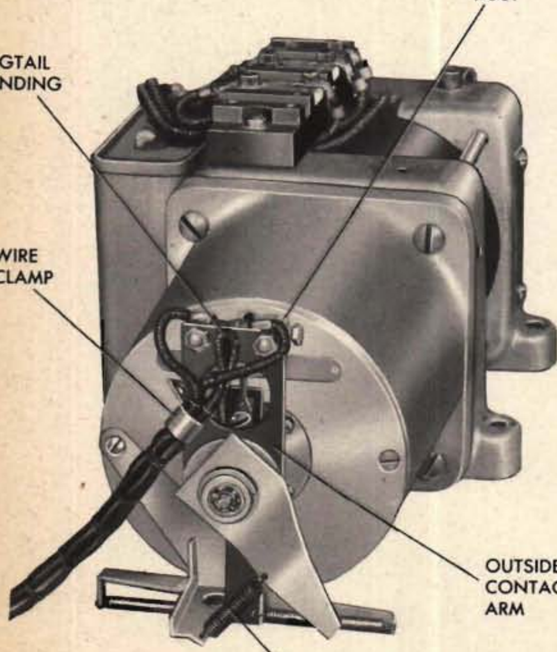
SMALL GEAR BOX

3 Drive out the taper pin to remove the crank. Pull out the cotter pin in order to remove the crank roller.

4 Separate the plates of the small gear box to remove the second locking-disk assembly and the second intermittent pinion.

Disassembly: Compensated follow-up

Usually the motor and the compensator are removed from the instrument as a unit, while the control gearing is removed separately.



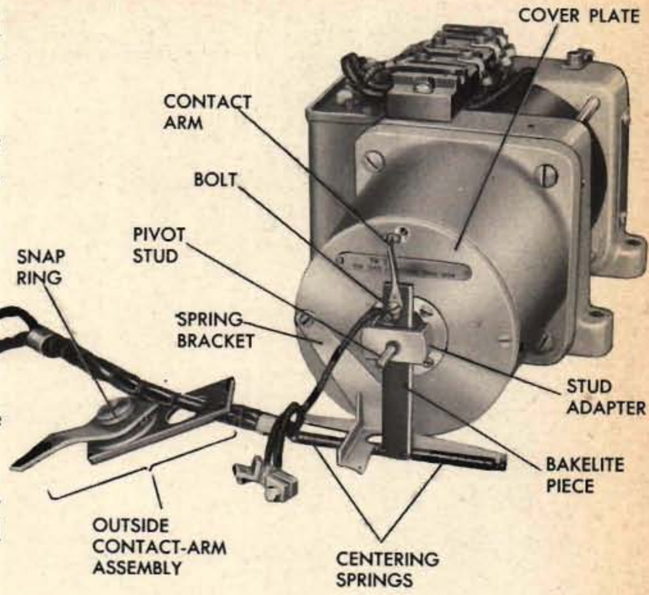
Removing the contacts

1 Disconnect the pigtail wiring from the terminal block and unclamp it from the motor and from the compensator housing; unhook the lever-arm spring.

2 Remove the contact posts and the pigtail wiring from the outside contact arm. Tag the terminals for identification. Cut the thread binding the center-contact pigtail lead to the outside contact arm.

3 Pull the cotter pin out of the pivot stud and remove the outside contact-arm assembly.

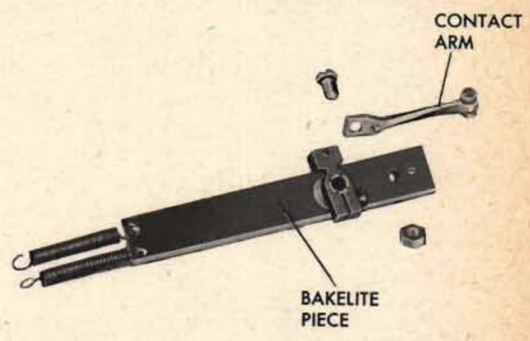
4 Remove the snap ring and separate the lever arm from the outside contact arm.



5 Loosen the center-arm clamp; unhook the centering springs.

6 Take out the stud-adapter screws. Simultaneously, remove the stud adapter and center contact-arm assembly.

7 Remove the bolt which holds the pigtail terminal and center contact arm to the bakelite piece, and take off the contact arm.



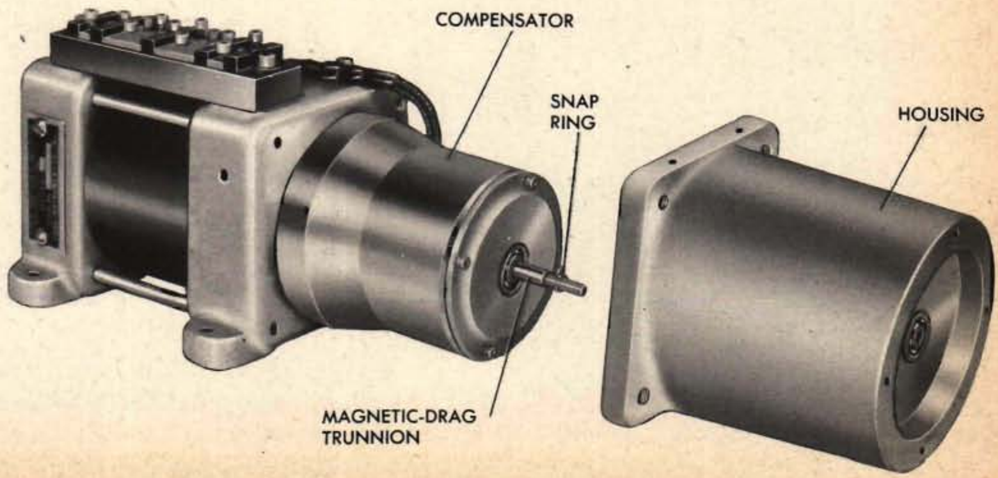
Removing and disassembling the compensator

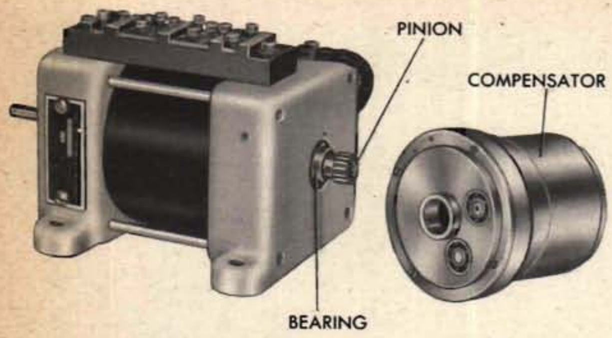
1 Remove the spring bracket.

2 Remove the cover plate from the housing.

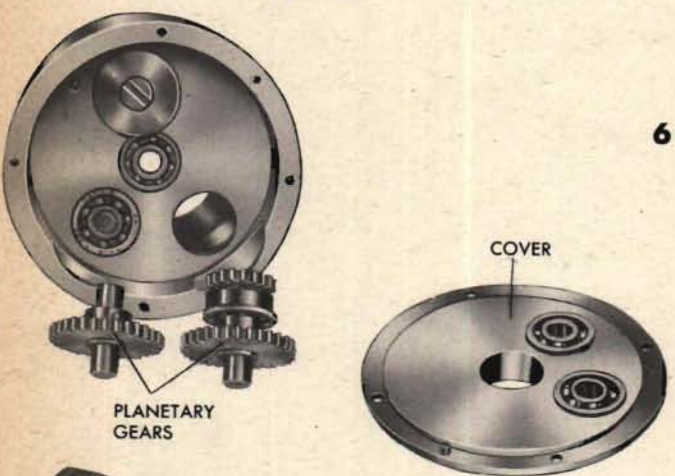
3 In some units a split hub is used to attach a spiral spring to the magnetic-drag trunnion. Carefully spread the split hub to remove it from the shaft.

4 Remove the compensator housing.

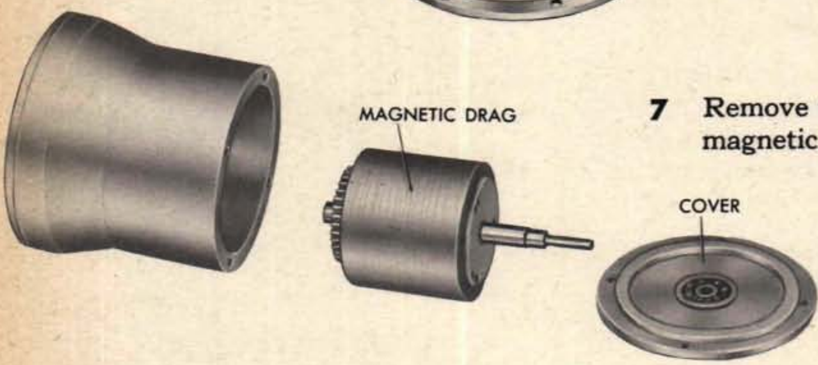




5 Carefully pull the compensator off the bearing on the motor shaft. If the compensator does not come off easily, carefully pry it, using two levers simultaneously to avoid bending the shaft or damaging the pinion.



6 Remove the cover on the motor end of the compensator and lift out the planetary gears.



7 Remove the other cover and lift out the magnetic drag.

CONTROL GEARING

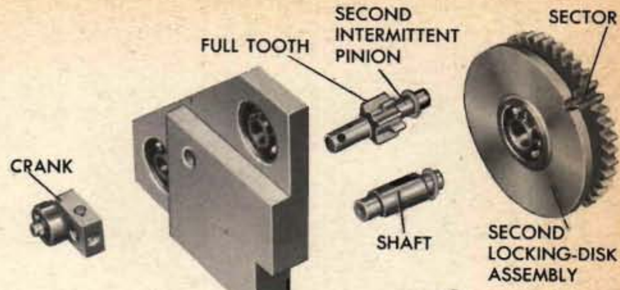
Disassembling the control gearing

Sometimes the follow-up control gearing is mounted on its own plate; sometimes it is mounted on a larger plate which is an integral part of the instrument.

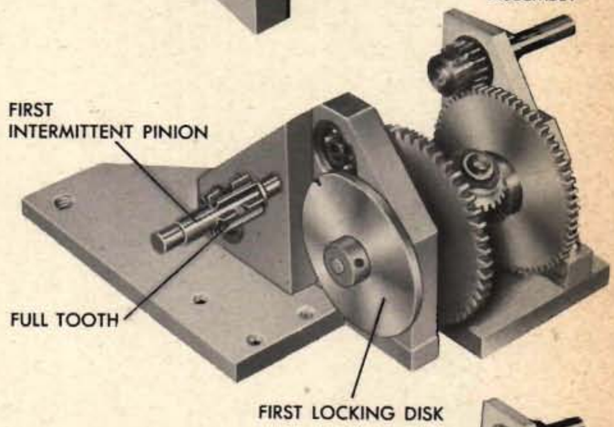
1 Remove the two screws from underneath and lift off the small plate which supports the outer end of the second intermittent pinion.

2 Rotate the second locking-disk assembly until the sector engages a full tooth on the second intermittent pinion. Remove the second locking-disk assembly and its supporting shaft.

3 Drive the taper pin out of the crank; remove the crank and the second intermittent pinion.

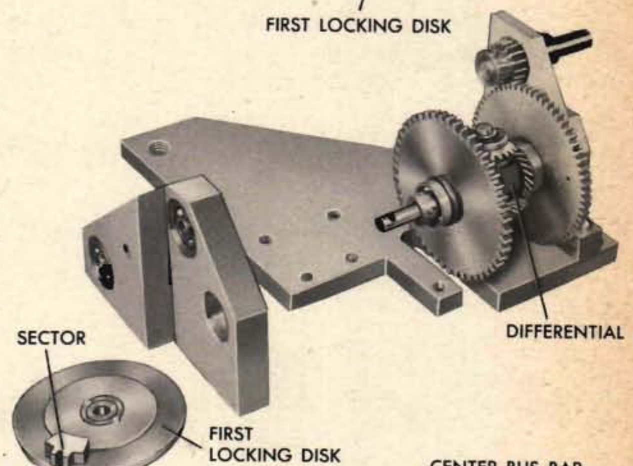


4 Lift out the first intermittent pinion. To do so, it is necessary to rotate the first locking disk, which is on the differential spider, until the sector and a full tooth are in mesh.



5 Drive the taper pin out of the hub of the first locking disk, and remove the disk.

6 Remove the two screws from underneath and lift off the plate which supports one end of the differential. Remove the differential.



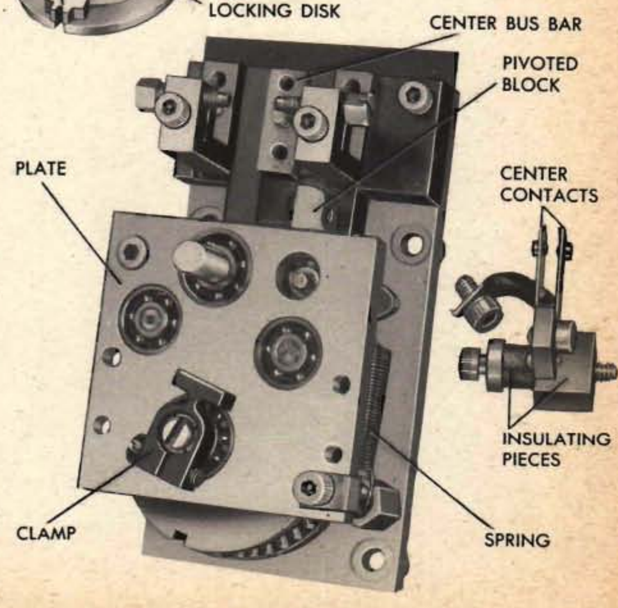
Disassembly: Oscillating follow-up

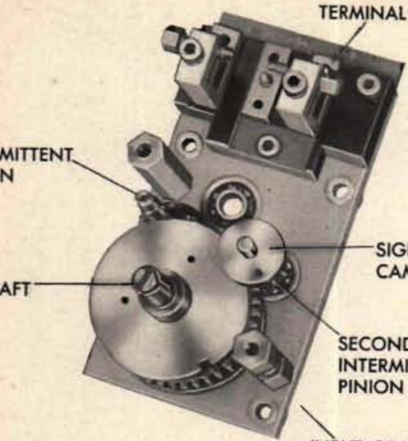
Consult the instrument instruction book for removing the component parts of the follow-up, namely, the control unit, the follow-up differential, and the motor.

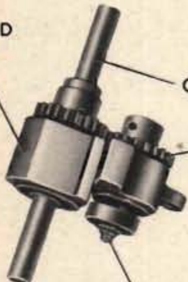
Disassembling the control unit

1 Remove the center contacts and the insulating pieces from the pivoted block, and disconnect the pigtail terminal from the center bus bar. Unhook the spring.

2 Remove the clamp. Remove the two screws securing the plate to the posts, and then lift off the plate.







3 Lift out the signal cam.

4 Lift out the pivoted block. Push the oscillator shaft out of the bearings. To remove the eccentric shaft, it is necessary to drive out the taper pin and remove the spur gear.

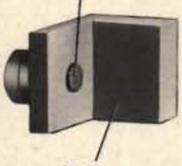
5 Remove the gear which is clamped on the input shaft.

6 Lift out the input shaft and the first intermittent pinion together.

7 Remove the terminal block from the mounting plate.

Repairing and replacing the parts

Repairing a contact



If a contact is pitted, polish it down to a smooth unmarred finish with a fine oilstone or fine abrasive paper. Keep the contact surface square. Lay the abrasive paper on a flat plate and rub the contact across it. After polishing, clean the contact to remove all abrasive particles. Never use an abrasive coarse enough to leave visible scratch marks, since scratches favor arcing, causing the contacts to become pitted and dirty all over again.

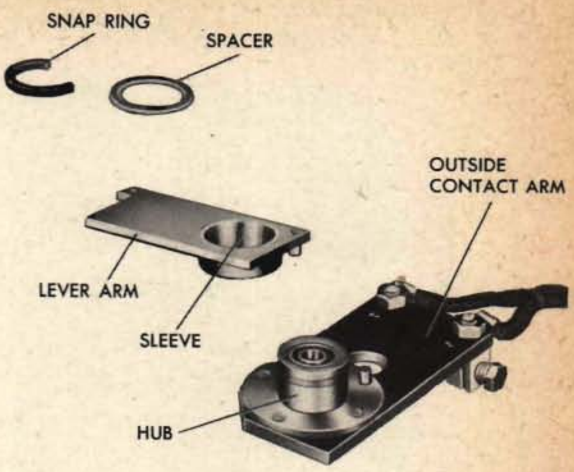
If a contact is loose in a post, rivet the end of the shank which protrudes through the post.

If the contact on the center arm is loose, braze it with an approved silver solder.

To tighten an adjustable-contact screw which is loose in its post, back out the screw until it no longer bridges the split. Using a small pry, open the split *slightly* so the screw fits snugly.

Repairing an outside contact arm

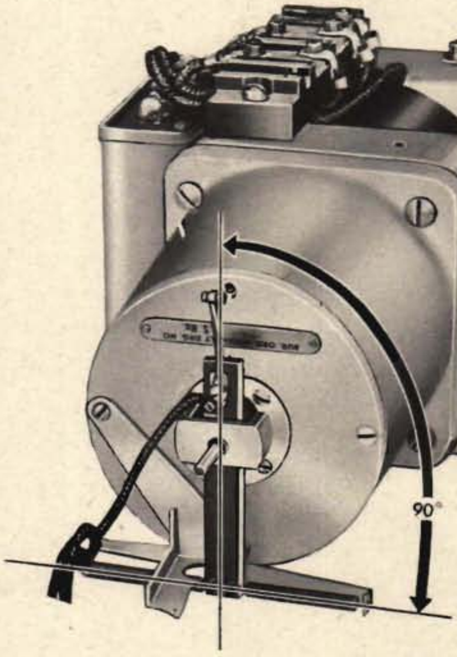
Separate the lever arm from the contact arm. Examine the steel sleeve riveted to the lever arm; remove even the smallest burrs. *Polish* the inside of the sleeve and the end which bears against the hub. *Polish* the aluminum hub riveted to the outside contact arm. Lubricate the hub with *one* drop of an approved lubricant before reassembly. If there is a spacer between the sleeve and the snap ring, be sure that it is smooth and flat. Make sure that there are no sharp edges on the snap ring.



Replacing springs

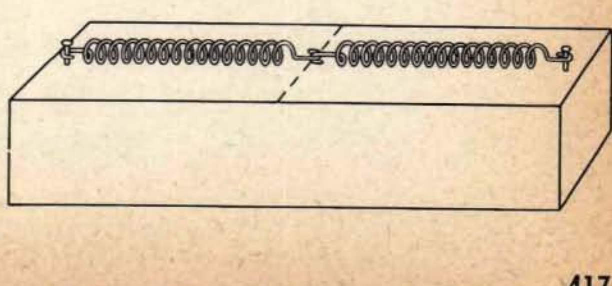
Replace rusted springs. Put a thin film of oil on a new spring to protect it against corrosion.

When replacing a centering spring, check that it matches its mate in length and strength. A rough check may be made by observing whether the center contact assembly is at right angles to the centering springs.

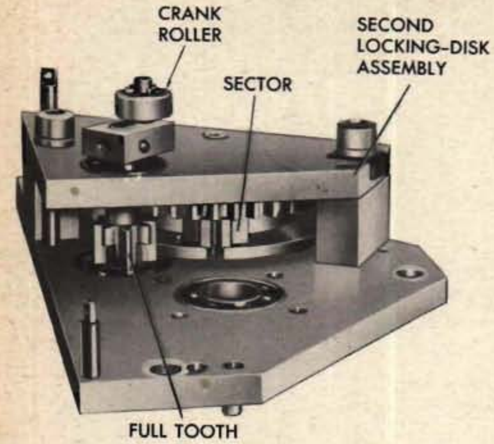


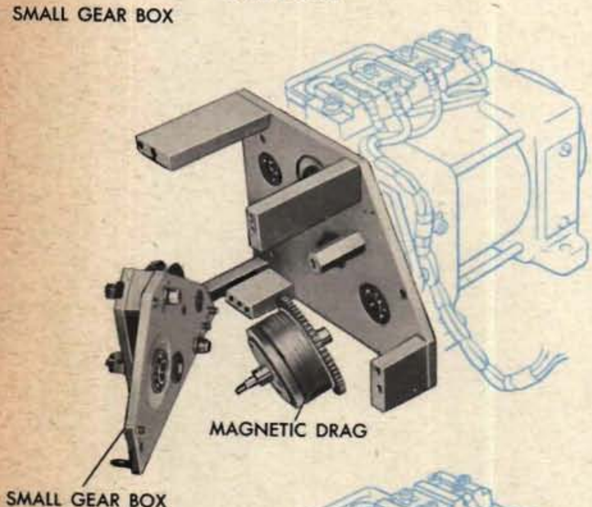
For a more accurate check, remove the springs from the unit. Measure and compare their free length. If their free lengths are equal, check their strength as follows: Measure the distance between the studs on which the springs are hooked. Drive two nails into a piece of wood, spacing them the same distance apart as the studs. Make a mark midway between these two nails. Hook the springs to each other and then to the nails. The point at which the two springs are hooked together should be exactly midway between the nails. If this point is slightly off center, compensate by carefully stretching the shorter of the two springs. If there is a large difference or if the springs are weak or rusted, they should be replaced.

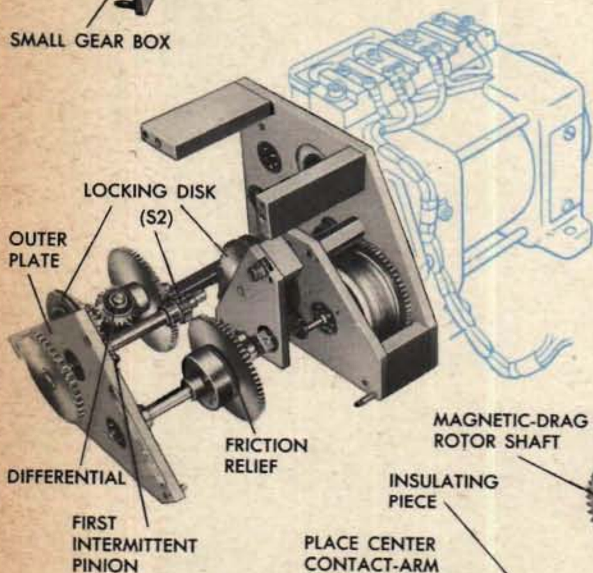
NOTE:
For additional instructions on repair work, refer to the chapters on *Wiring,* page 380; *The Servo Motor,* page 426; *Shaft Lines,* page 92; and *The Bevel Gear Differential,* page 174. The instructions given for the magnetic damper, page 441, apply in general for magnetic drags.



Reassembly: Magnetic drag follow-up







Reassembling the control unit

1 Assemble the second intermittent pinion and the second locking-disk assembly between the plates, meshing a full tooth with the sector.

2 Put the crank roller on the crank and hold it in place with a cotter pin. Pin the crank to the second intermittent pinion.

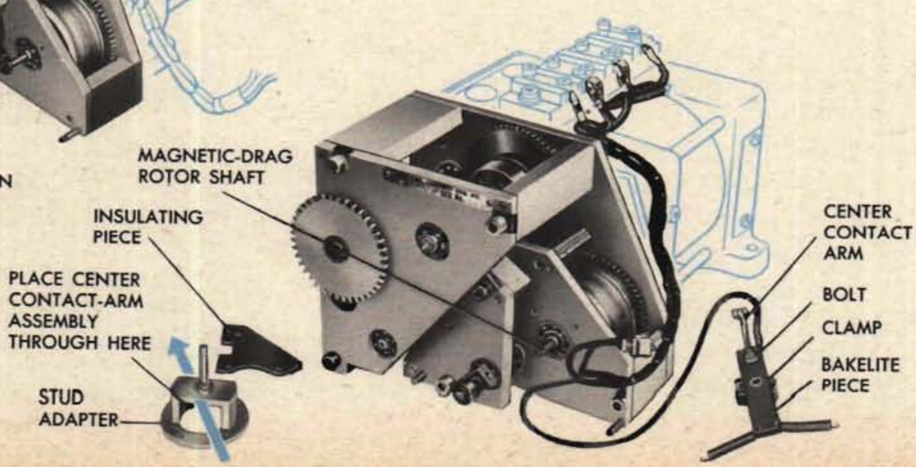
3 Put the magnetic drag in place. Mount the small gear box.

4 Simultaneously replace the differential, the first intermittent pinion, the friction relief (S1), shaft (S2), and the outer plate. In order to obtain the correct relationship between the two locking disks, it is essential to assemble the first intermittent pinion so that the sectors on both locking disks will simultaneously be in mesh with full teeth of both intermittent pinions.

Replacing the contacts

1 Bolt the center contact pigtail terminal and the center contact arm to the bakelite piece.

2 Place the center contact-arm assembly through the stud adapter as indicated; then push it on the magnetic drag rotor shaft, and tighten the clamp. Secure the stud adapter and the insulating piece to the plate. Hook the centering springs to the posts.

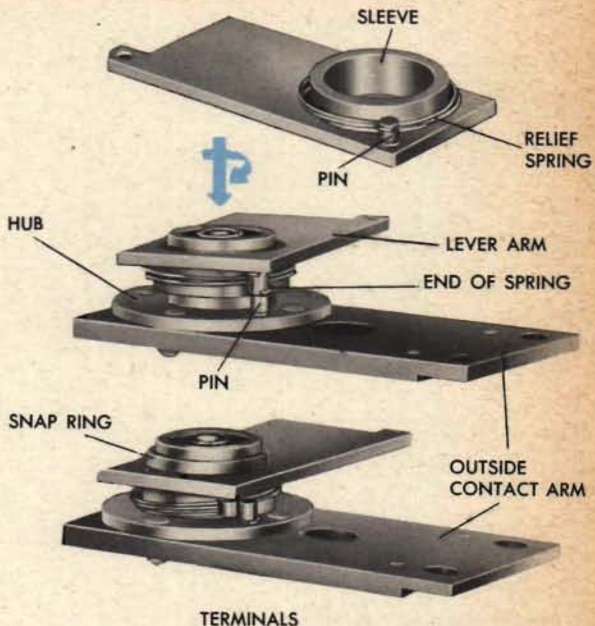


3 Place the relief spring over the lever-arm sleeve, temporarily hooking both ends on the pin.

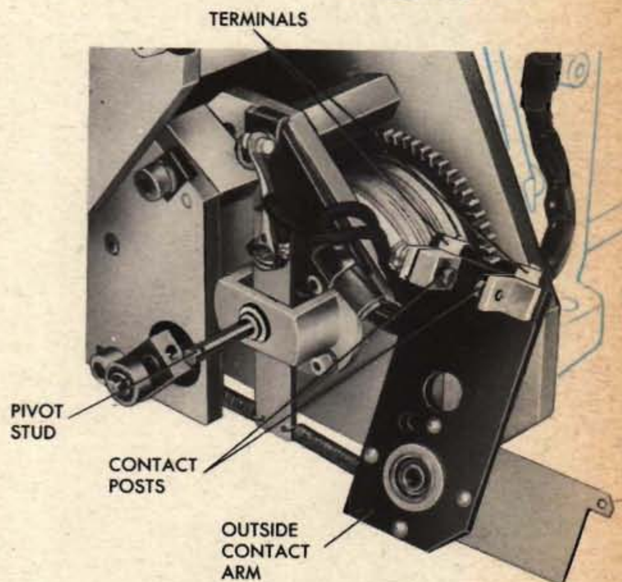
4 Apply one drop of approved lubricant to the sleeve, and slide the hub of the outside contact arm into the sleeve.

5 Holding the arms so that the pins meet end to end, slide one end of the relief spring onto the outside contact-arm pin as shown. Turn the lever arm clockwise and push it down into place.

6 Put on the spacer and snap ring.

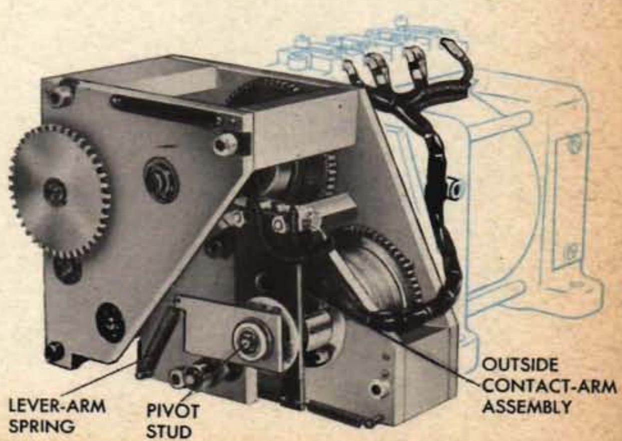


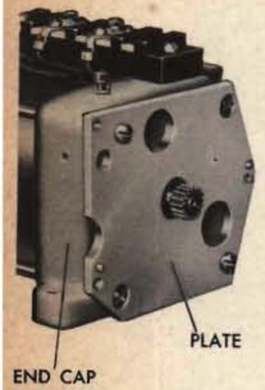
7 Mount the terminals and contact posts in their places on the outside contact arm.



8 Mount the outside contact-arm assembly on the pivot stud and secure it with a spacer and cotter pin.

9 Hook the spring on the lever arm and to the post.



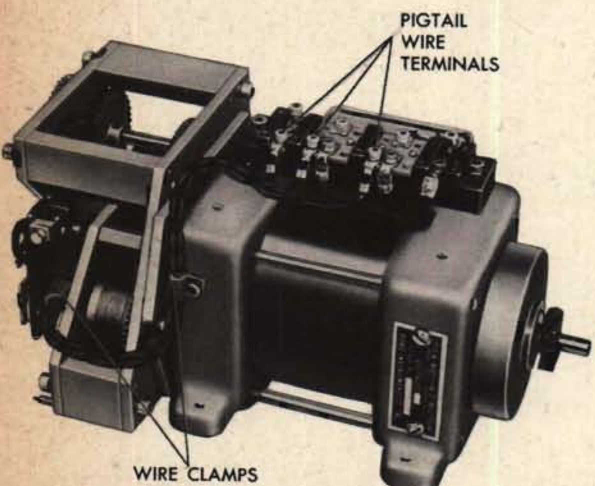


Replacing the control unit

1 Mount the plate on the motor end cap.

2 Mount the control unit on the plate.

3 Attach the pigtail wires to the terminal block according to the designations stamped on the terminal lugs. Clamp the pigtail wire cable.

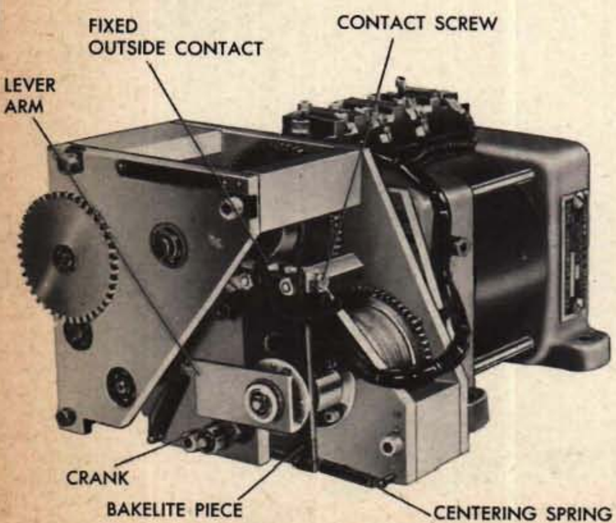


Adjusting the contacts

1 By using matched centering springs (see page 417), make the bakelite piece of the center contact-arm assembly stand at right angles to the centering springs. The center contact arm should be aligned with the bakelite piece.

2 Set and wedge the crank parallel to the lever arm, with the roller toward the spring. The center and fixed outside contact surfaces should be parallel and about 0.005 inch apart. If they are not, loosen the fixed outside contact post and shift it within the clearance hole.

3 Turn the contact screw until this contact also is about 0.005 inch from the center contact, making a total gap of about 0.010 inch. If this outside contact is askew, align it by shifting the contact post.



Bench checking the unit

1 Check the unit against the assembly drawing.

2 The center contact arm should be at right angles to the centering springs when the outside contacts are not touching the center contact.

3 The contact surfaces should meet flush and in line.

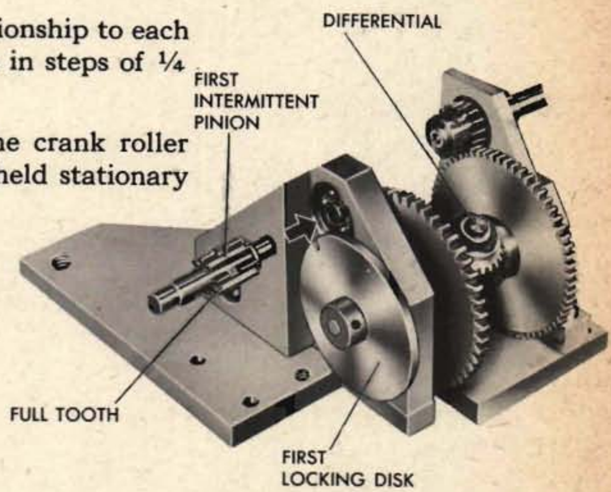
4 The contact surfaces should be clean.

5 When the crank is parallel to the lever arm and the roller is toward the spring, the center contact should be centralized.

6 The gears and bearings should be clean, lubricated, and free to turn. End shake of shafts and lost motion in gear meshes should be at a minimum.

7 The locking disks should be in correct relationship to each other. This is indicated if the crank moves in steps of 1/4 revolution.

8 The follow-up should synchronize with the crank roller toward the spring when the input gear is held stationary and the power is ON.



Reassembly: Compensated follow-up

Reassembling the control gearing

1 Mount the differential between the two plates.

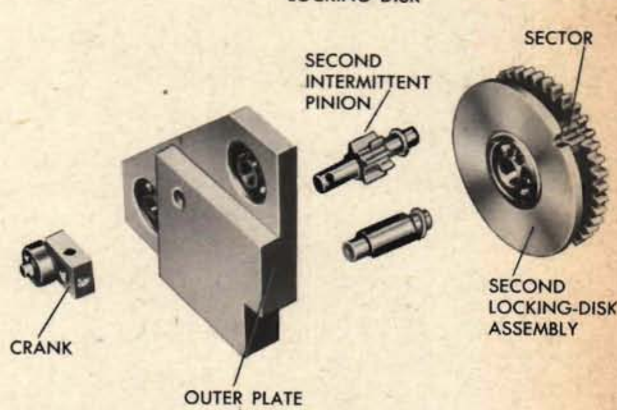
2 Pin the first locking disk to the spider shaft, hub side out.

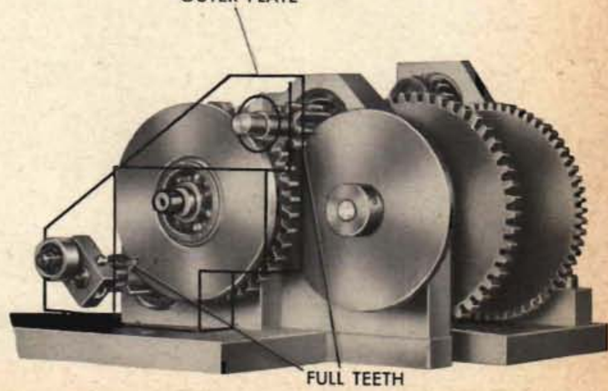
3 Mount the first intermittent pinion, meshing a full tooth with the sector.

4 Put the second intermittent pinion in the outer plate and pin the crank to the shaft.

5 Mount the second locking-disk assembly on its shaft in the outer plate with the disk toward the plate.

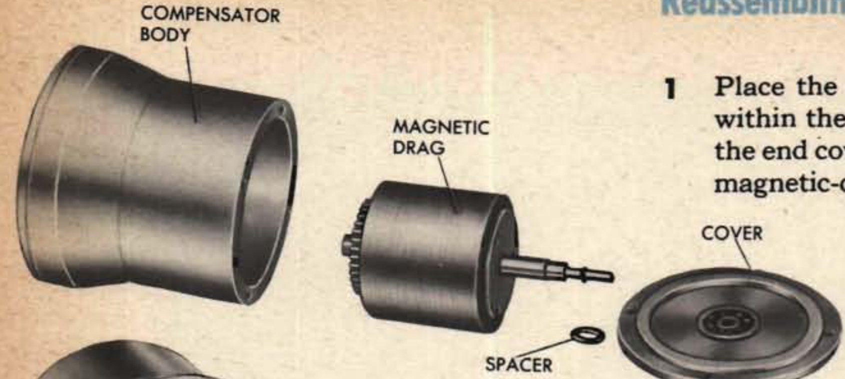
6 Mount the outer plate. In order to obtain the correct relationship between the two locking disks, it is essential for the sectors on both locking disks to mesh simultaneously with full teeth on the intermittent pinions.





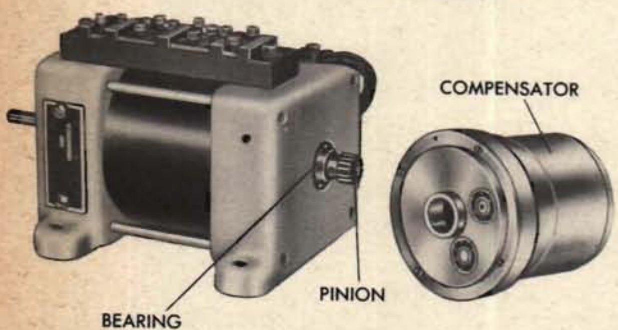
Reassembling the compensator

1 Place the magnetic drag and its spacers within the compensator body and secure the end cover. Check the end shake of the magnetic-drag body.



2 Put the gears and spacers in place in the compensator body. Be sure the marked teeth mesh. Secure the other cover. Check the end shake of the shafts.

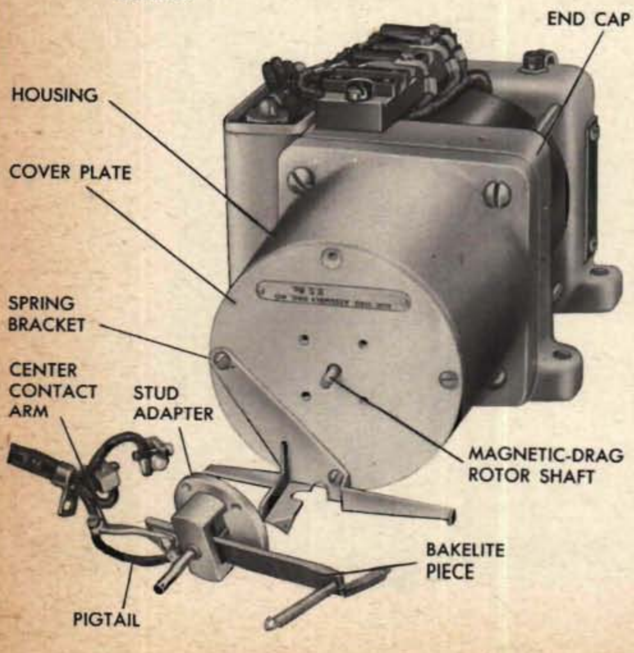
3 Carefully push the compensator onto the bearing on the motor shaft and into mesh with the pinion.



4 Slip the housing over the compensator and secure it to the motor end cap.

5 If the unit had a spiral spring in the housing, push it back in place on the magnetic-drag trunnion.

6 Secure the cover plate and the spring bracket to the housing.



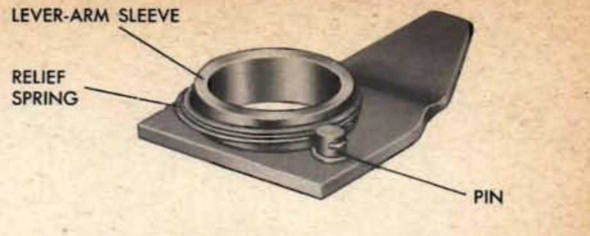
Replacing the contacts

1 Bolt the center contact pigtail terminal and the center contact arm to the bakelite piece.

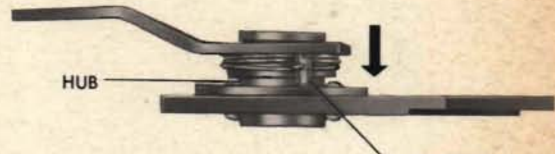
2 Place the center contact assembly through the adapter; then push it on the magnetic-drag rotor shaft and tighten the clamp.

3 Secure the adapter with screws, and hook the centering springs to the spring bracket.

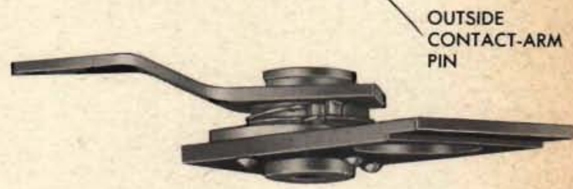
4 Place the relief spring over the lever-arm sleeve, temporarily hooking both ends on the pin.



5 Put one drop of approved lubricant in the sleeve and slide the lever arm onto the outside contact-arm hub.

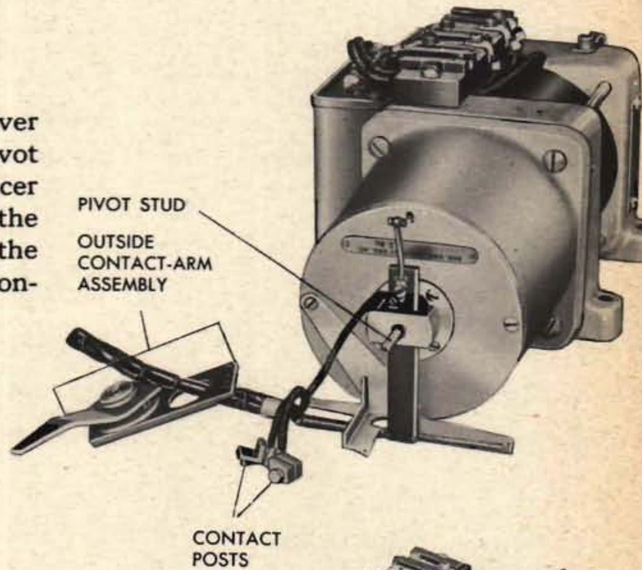


6 Holding the arms so that the pins meet end to end, slide one end of the relief spring onto the outside contact-arm pin. Turn the lever arm counterclockwise and push it down into place.



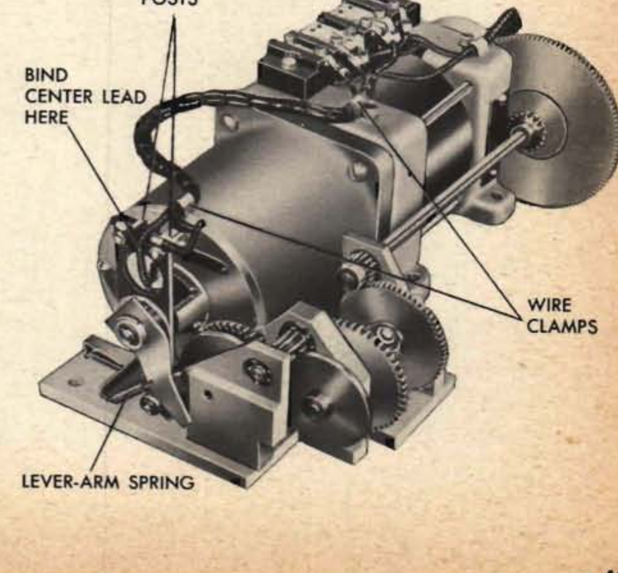
7 Put on the spacer and the snap ring.

8 Slide the outside contact assembly over the pigtail wiring; mount it on the pivot stud and secure it in place with a spacer and cotter pin. Hook the spring to the lever arm and to the bracket. Bind the center contact pigtail to the outside contact arm.



9 Mount the contact posts and the pigtail wire terminals on the outside contact arm according to the tags attached at disassembly.

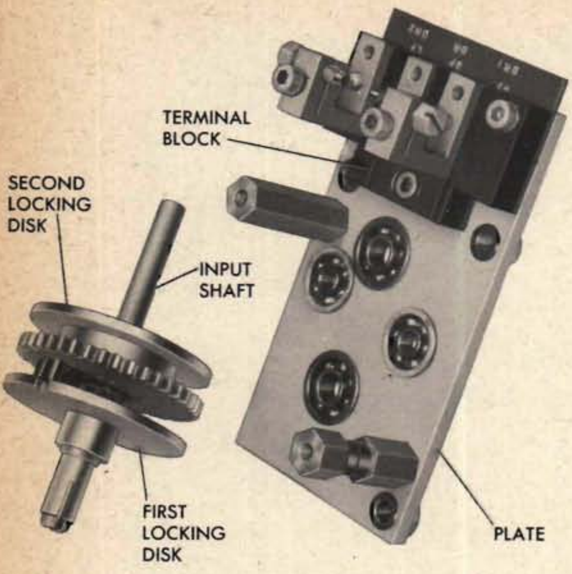
10 Clamp the pigtail wiring in place.



ADJUST the contacts of the compensated follow-up in the same manner as those on the magnetic-drag follow-up, page 420.

BENCH CHECK the compensated follow-up in the same manner as the magnetic-drag follow-up, page 420.

Reassembly: Oscillating follow-up control



1 Mount the terminal block on the plate.

2 Place the locking-disk assemblies on the input shaft in the order shown.

3 Mount the input shaft in the plate. Clamp the input gear on the shaft.

4 Put the eccentric shaft in the pivoted block, and pin the gear in place. Push the oscillator shaft into the pivoted block.

5 Mount the pivoted block in the plate.

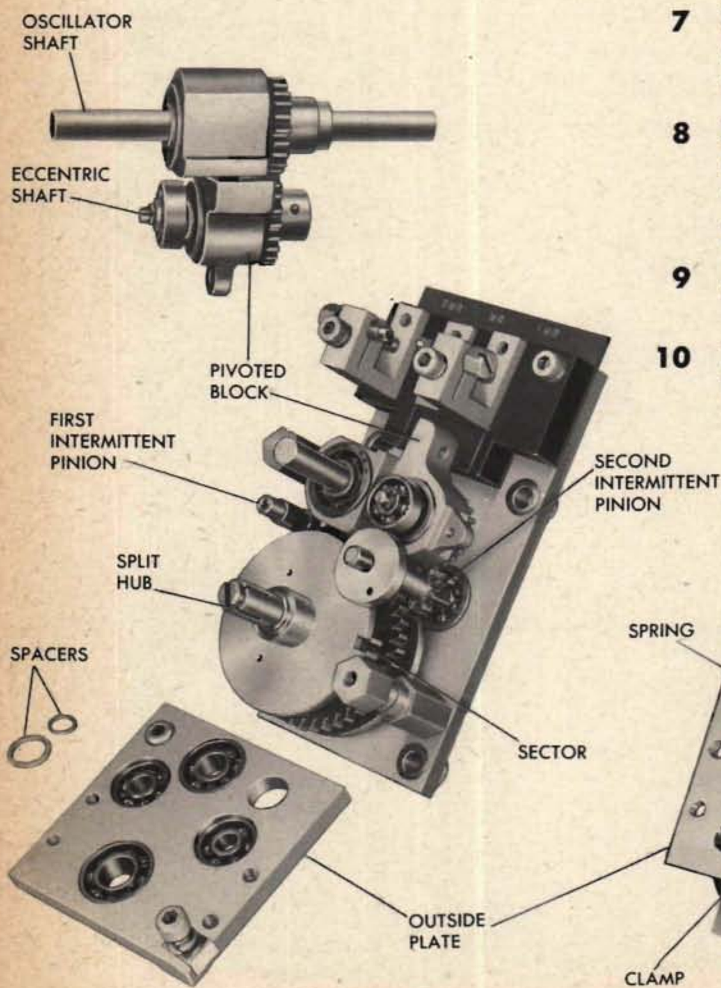
6 Insert the first and second intermittent pinions so that full teeth mesh with both sectors simultaneously.

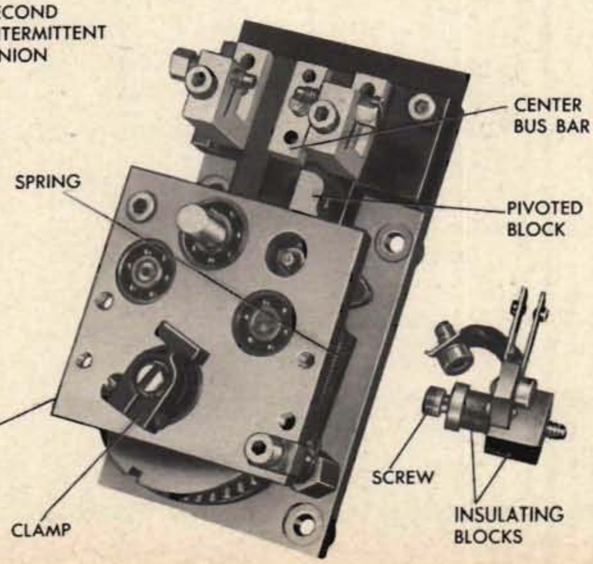
7 Place the spacers on their respective shafts and mount the outside plate. Put the clamp on the split hub.

8 Hold the center contact and the insulating blocks together. Pass the screw through them and secure them to the pivoted block.

9 Attach the pigtail terminal to the center bus bar.

10 Hook the spring to the post and to the block.





Adjusting the contacts

Only an approximate adjustment can be obtained on the bench. Consult the instrument OP for making the final adjustments in the instrument.

1 Displace the center contacts to one side by turning the input shaft.

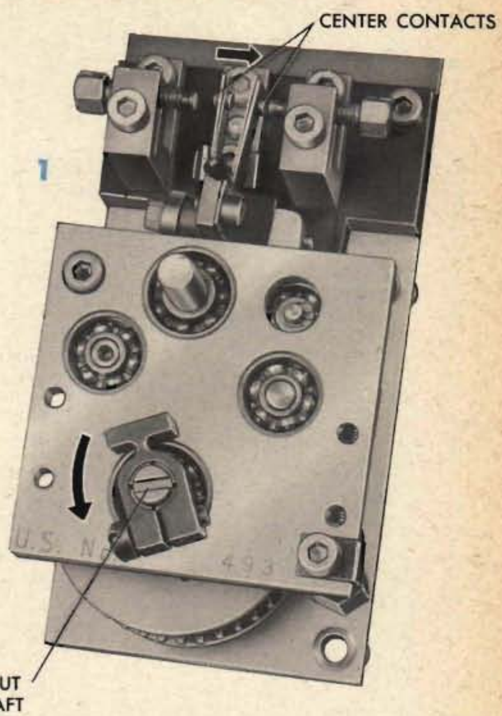
2 Turn the oscillator shaft until the center contacts are displaced the maximum amount toward the center.

3 Turn the contact screw until it just touches the center contact. Then turn the contact screw in by one half-revolution.

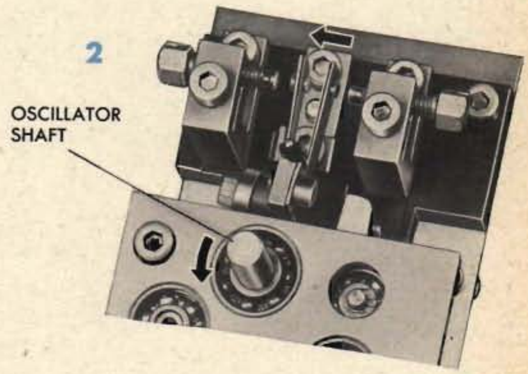
4 With the center contacts thrown to the opposite side, repeat steps 2 and 3 for the other contact screw.

This process positions the outside contacts equidistant from the working center of the oscillating center contact. To preserve this relationship when making the final adjustments, always move both contact screws equally.

1



2



Bench checking the unit

Unless a special test fixture is available, the follow-up cannot be run on the bench.

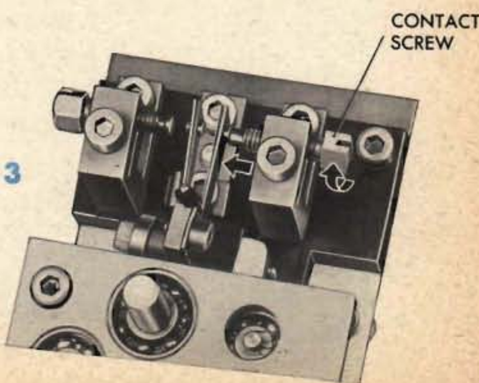
1 Check the unit against the assembly drawing.

2 The gears and bearings should be clean, lubricated, and free to turn. End shake of shafts and lost motion in gear meshes should be at a minimum.

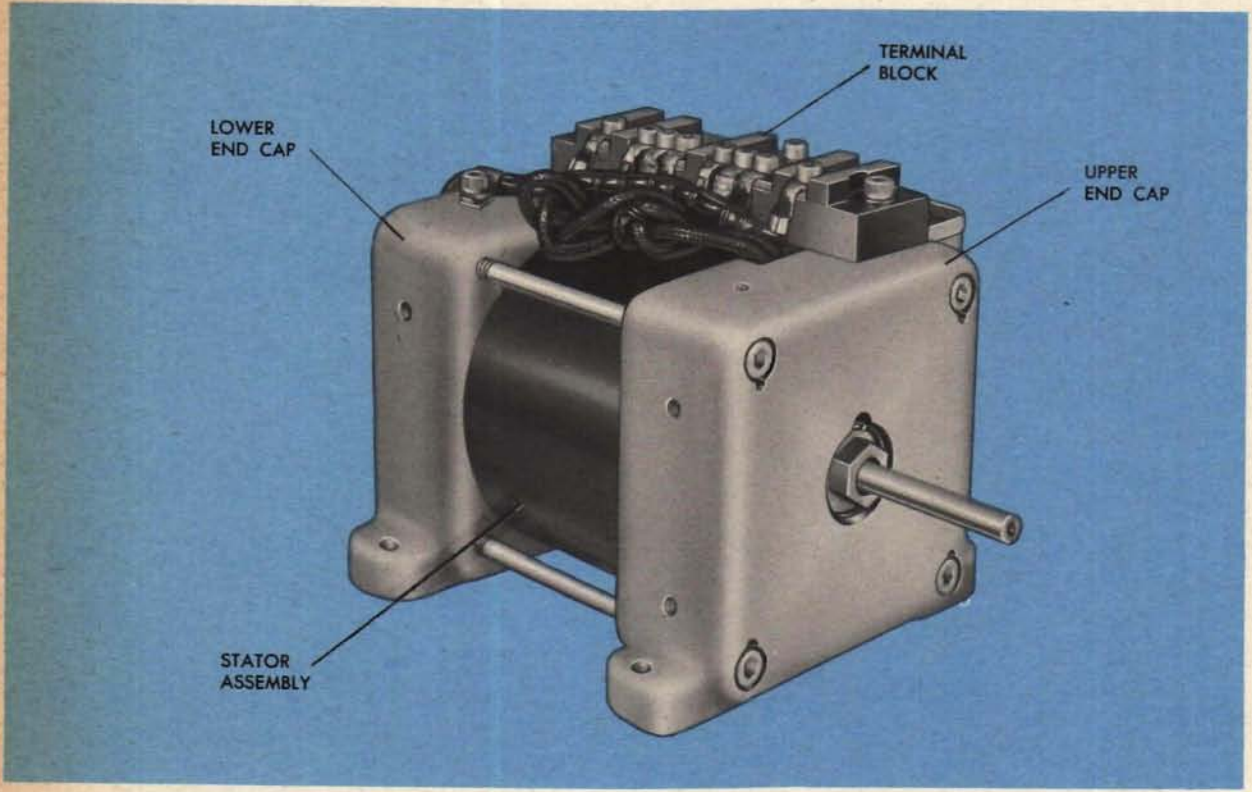
3 The contact surfaces should be clean, meet flush, and be in line.

4 The locking disks should be in correct relationship to each other. This is indicated if the cam moves in steps of ¼ revolution.

3



THE SERVO MOTOR



The servo motor is used most frequently in various types of follow-ups where it functions as a torque amplifier. It is also used as a time motor to turn the time shaft line. The servo motor is an induction-type motor in which the rotor is not connected directly to a power supply but is turned by the action of a magnetic field set up by current flowing in two stator coils.

The servo motor can be checked but not repaired while it is in the instrument. Because its removal may disturb the shafting to other units, use the instrument OP to check both the input wiring and the output shafting to make sure that the trouble is actually in the motor.

This chapter is concerned only with the motor. It assumes that all associated equipment such as wiring, capacitors, gearing, or follow-ups, have been checked and the motor is known to be defective. Always REPLACE a defective motor with a new motor when a replacement is available.

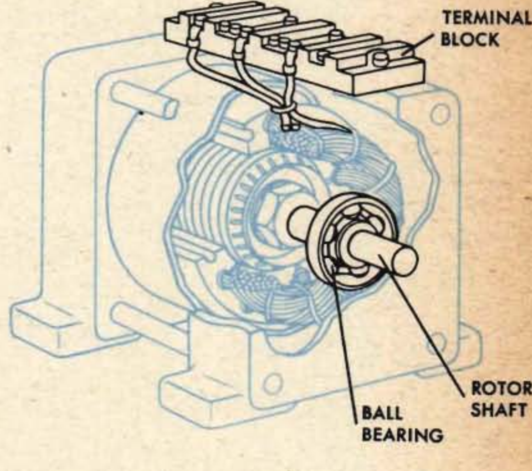
If no replacement is at hand, the following symptoms should be checked, with the motor either in the instrument or on the bench, to determine whether it can be repaired.

Typical symptoms

Noisy operation

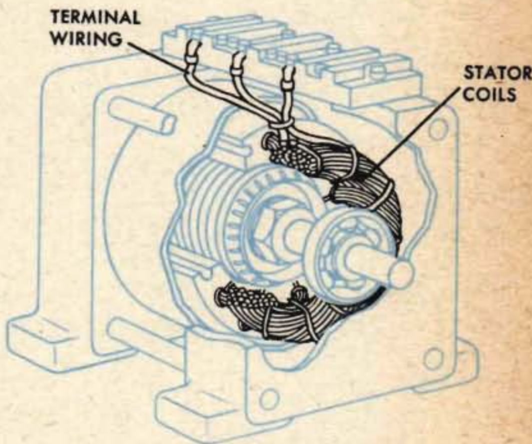
This is detected by running the motor. It can be checked with the motor in place if the motor can be disconnected from the associated gearing. If this check cannot be made in place, the motor must be removed. In either case, the motor must be disassembled and inspected for a bent rotor shaft or damaged or dirty bearings.

If the motor has a reduction gear box, the trouble may be in the reduction gears or bearings. Repair of a gear box usually requires its removal from the motor.



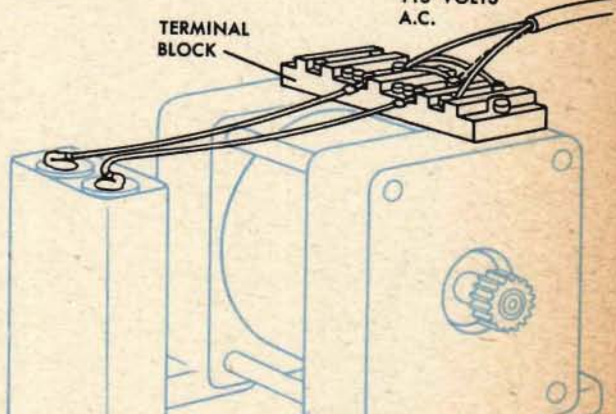
Erratic operation

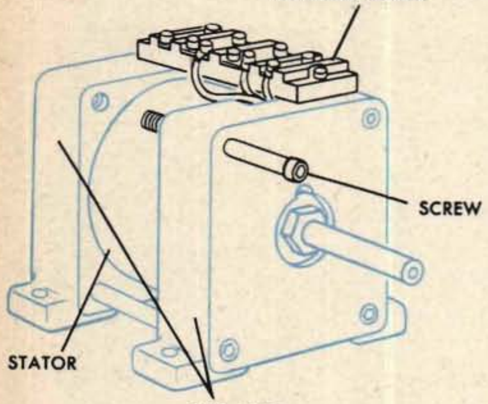
Check the wiring for intermittent short circuits or open circuits. Try to spin the motor shaft by hand. If the motor jams or sticks on this test, the trouble is probably due to damaged or dirty rotor bearings or a bent rotor shaft. Dirty bearings may cause the motor to start slowly. The motor should be disassembled to clean dirty bearings or to straighten a bent shaft. Damaged bearings or a badly bent shaft require replacement.

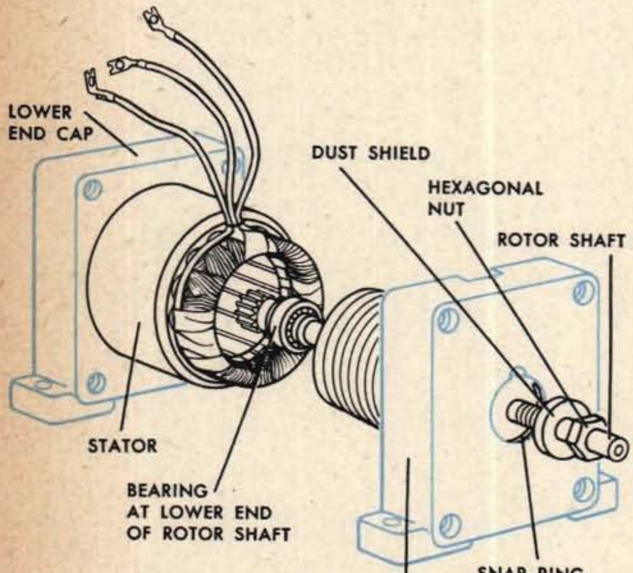


Motor does not drive

Using a test capacitor of the proper value, connect the motor to a 115-volt A.C. supply. If the motor does not run, a stator coil may be burned out, or open, or a lead from the motor terminal block may be open. Inspect the leads for damage. If they are in satisfactory condition, test the stator coils with an ohmmeter and compare the resistance readings with the values given on the assembly drawing. If a stator coil is burned out or open, the motor should be replaced.







Disassembling the unit

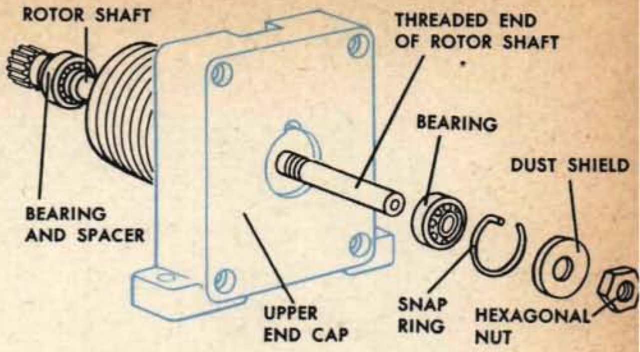
1. Remove the screws holding the motor leads to the terminal block.
2. Remove the terminal block.
3. Remove the four long screws which hold the end caps and stator together.
4. If a gear on the rotor shaft will not permit the shaft to slide through the hole in the lower end cap, remove the gear.
5. Remove the upper end cap from the stator shell. If necessary, start the cap by tapping it lightly with a plastic hammer. The rotor shaft is held in the upper end cap and will come out with it.
6. Remove the hexagonal nut on the rotor shaft near the bearing in the upper end cap.
7. Remove the dust shield.
8. Pull the rotor out of the bearing.
9. If the bearing is to be removed, remove the snap ring from the end cap.
10. Remove the stator from the lower end cap.
11. If either the bearing or the rotor is to be replaced, remove the bearing from the lower end of the rotor shaft.

Repair and replacement of parts

To straighten a bent rotor shaft, follow the procedure on page 69. Replace a burned out or open stator assembly. Replace worn or damaged bearings.

Reassembling the unit

1. Be sure all parts are clean. Wipe the surfaces free of dust and grit.
2. Place the bearing and its spacer on the lower end of the rotor shaft.

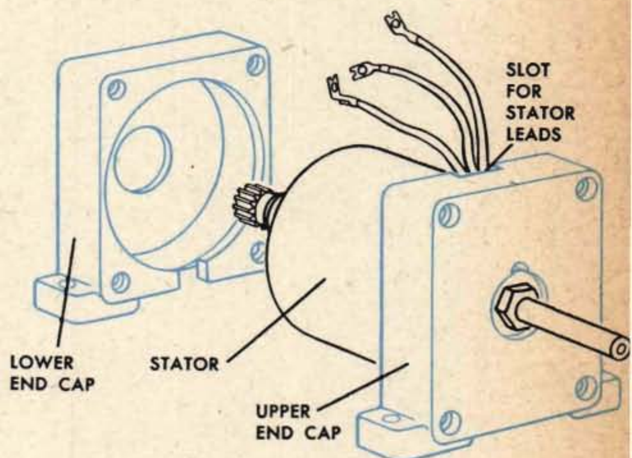


3 Place the other bearing in the upper end cap. Replace the snap ring.

4 Insert the threaded end of the rotor shaft through the upper end cap.

5 Place the dust shield over the bearing.

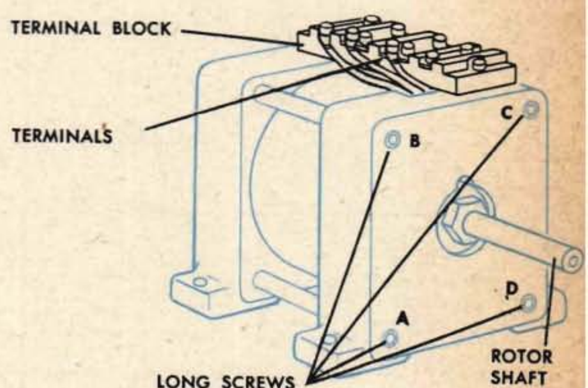
6 Replace the hexagonal nut on the threaded portion of the rotor shaft.



7 Fit the stator shell into the upper end cap. Be sure the stator leads are in the upper-end-cap slot.

8 Center the lower end cap on the shaft and move it into position over the bearing until it seats on the ridge of the stator shell.

9 Place the assembly on a flat surface to check that the mounting surfaces of the end caps are in the same plane.



10 Insert the four long screws and tighten them by hand.

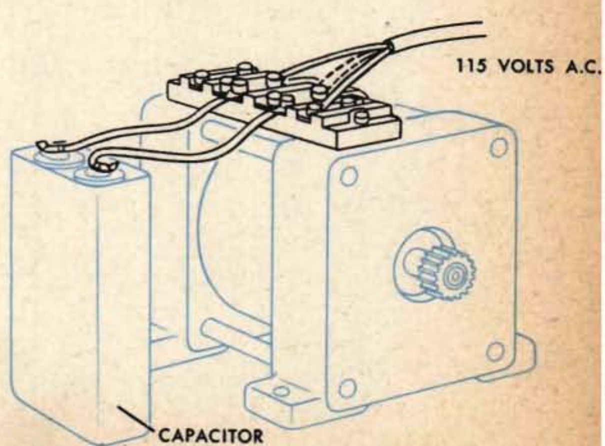
11 Spin the rotor shaft by hand. If the shaft does not spin freely, check that the end caps fit squarely on the stator. The shaft must spin freely before further assembly is attempted.

12 Tighten the long screws, not in rotation, but in the sequence A, C, B, D.

13 Screw the terminal block to the end caps.

14 Connect the terminals labeled L, C, and R, to the proper bus bars on the terminal block.

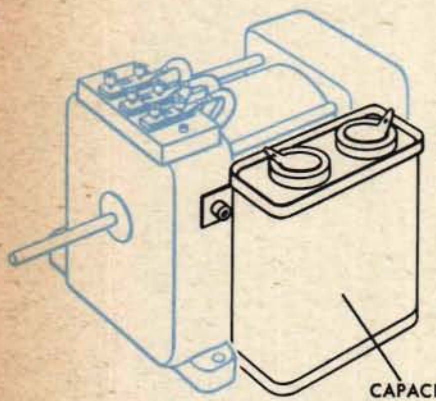
15 Put a drop of approved lubricant in each bearing.



Bench checking the unit

To check that the motor runs freely in both directions, place a test capacitor across the L and R terminals, and energize the motor by supplying 115-volt A.C. power first to the L and C terminals, and then to the R and C terminals.

THE CAPACITOR



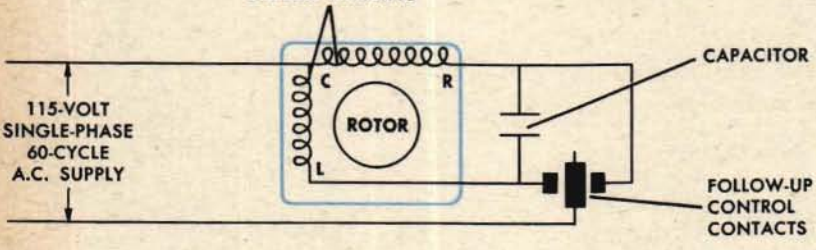
The capacitor, or condenser, supplies the necessary current phase lag to the second field coil to assure adequate starting and running torque.

The active parts of the capacitor are the metal plates, which conduct the current, and the insulating or "plate-spacing" medium. All are contained in a corrosion-resistant case with suitable mounting straps.

A most important fact to remember is that each servo installation calls for a specific size of condenser. Capacities vary with particular motors, from 1 to 16 microfarads.

If tests indicate that a servo is not operating properly, disconnect the condenser in use and substitute one which is known to be of the proper capacity and in good condition. If this clears the trouble, install a replacement condenser and discard the defective one.

CAUTION:
Before working on a condenser, turn the power supply OFF and discharge the condenser by short-circuiting the condenser terminals.



Typical symptoms

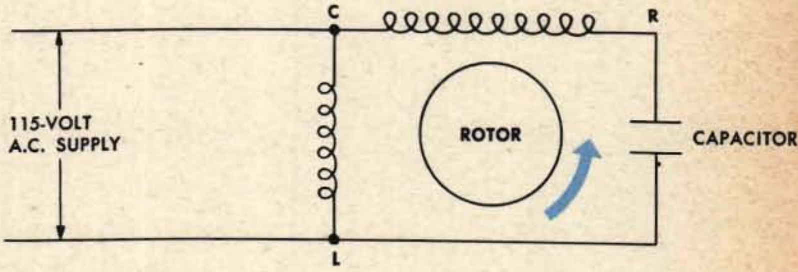
Because of the way in which a condenser is constructed, there is little or no possibility of effecting repairs to the unit itself. The obvious repair is "replacement."

However, in testing servos, the following symptoms may indicate faulty capacitors:

1. Servo does not drive.
2. Servo drives very sluggishly.
3. Servo overheats.

Locating the cause

1 If the servo does not drive with sufficient torque, the capacity of the condenser may be too low. This may be the result of a leak in the case, allowing the insulating medium to run out. Or, the leads to the metal plates may be "open." In this case capacity would be zero.



2 If the servo drives sluggishly, the condenser may be "partially short-circuited," allowing current to pass directly from one plate to the other. This condition may be located with a resistance measuring device (resistance bridge, ohmmeter, etc.).

3 Servo overheating may be due to a short-circuited condenser. In this case the insulating medium has broken down allowing the two plates of the condenser to make direct contact. Reference to the circuit diagram shows that such a condition passes all current through a single coil.

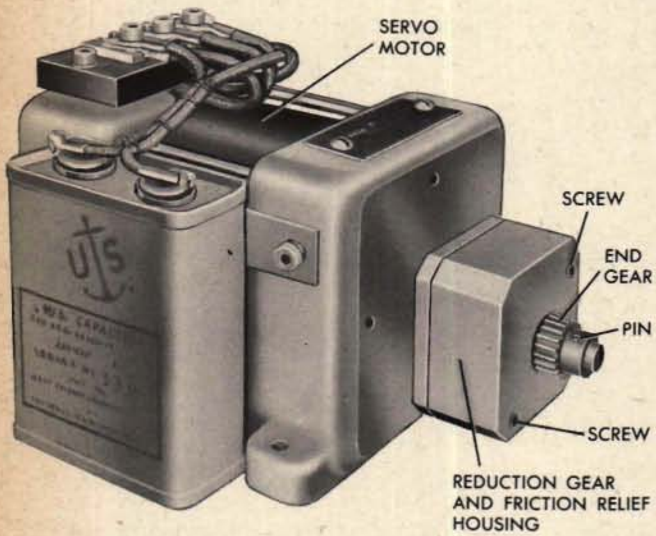
General practice

As previously indicated, there is very little that may be done in the way of actually "repairing" a condenser.

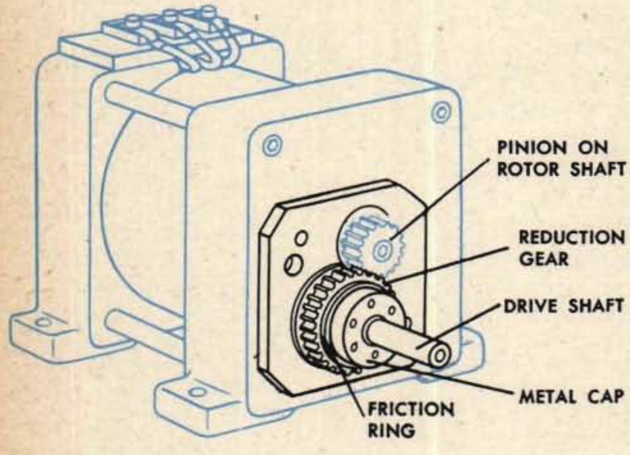
Replacement is the obvious solution.

Be certain that the replacement unit has the proper capacity. If the data on the name plate is not clear, measure the capacity. If, in an emergency, a condenser is used for which the characteristics are not available, make sure of two things: that minimum working voltage is 115 volts A.C., and that it has the proper capacity.

FRICTION RELIEF AND REDUCTION GEAR



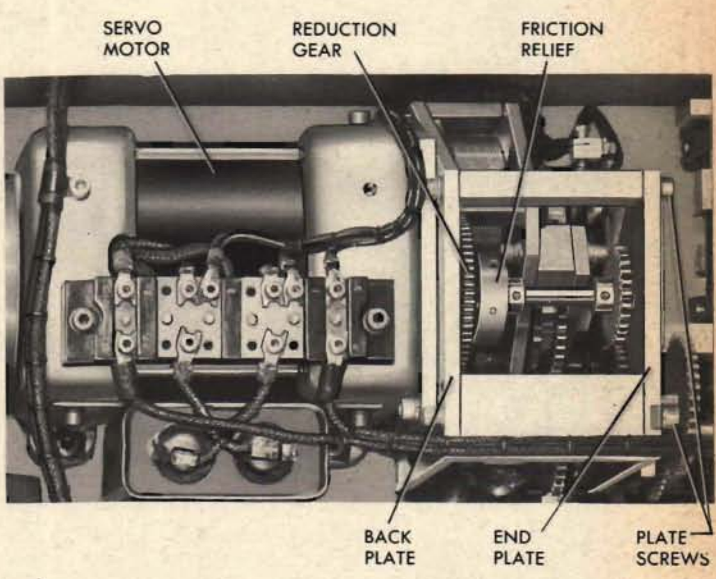
A servo motor drives through a reduction gear meshed with a pinion on the end of the rotor shaft. The reduction gear is usually mounted between two friction rings. A metal cap pinned to the drive shaft is drilled to hold six coil springs which press the friction rings firmly against the reduction gear. Dowels prevent the metal cap and the friction ring from turning separately. The friction relief will transmit any normal load, but when the load on the shaft line is too great, or when a limit stop is reached, the friction relief slips against the reduction gear.



The reduction gear and friction relief assembly may be mounted in a housing attached to the motor end cap, but it is usually mounted in the open with other gearing. A housed-type reduction gear and friction relief assembly can be removed from the motor by taking out the two long screws which hold the housing to the frame.

An open-type reduction gear and friction relief assembly can be removed by taking out the screws which hold the end plate, removing the plate, and carefully pulling the unit out of the bearing in the back plate.

Reduction-gear and friction-relief assemblies vary in size and construction details, but the maintenance problems are similar.



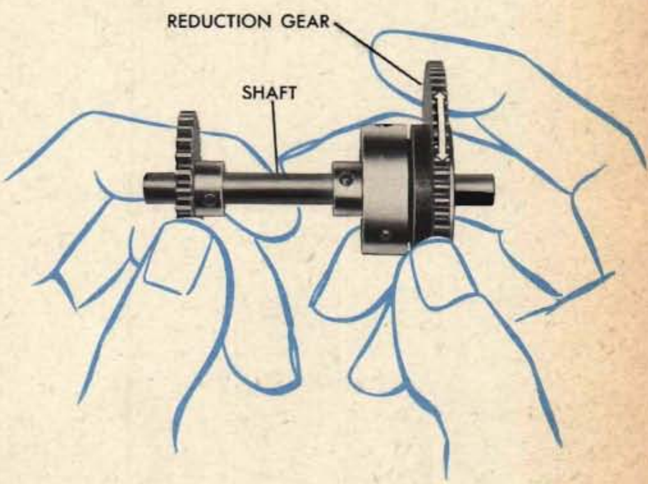
Typical symptoms

If trouble analysis of an instrument indicates faulty operation of a friction-relief and reduction-gear unit, look for one or more of the following typical symptoms:

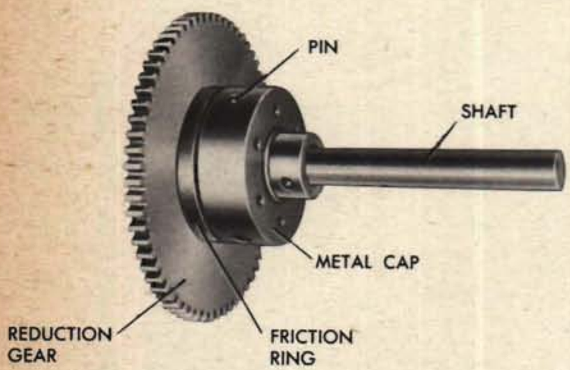
JAMMING: The reduction gear cannot be turned by hand when the shaft is held.

STICKING: The reduction gear does not turn smoothly when the shaft is held.

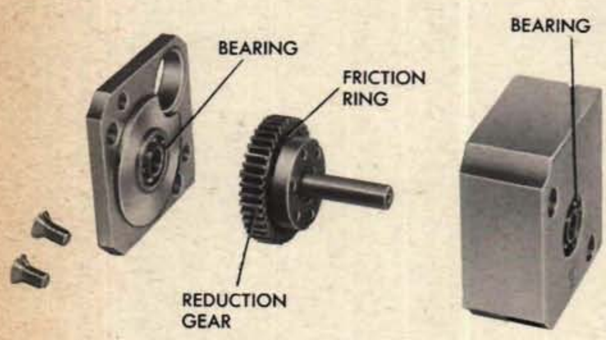
SLIPPING: The reduction gear slips on the friction ring when the load on the line is normal.



Locating the cause and repairing the parts

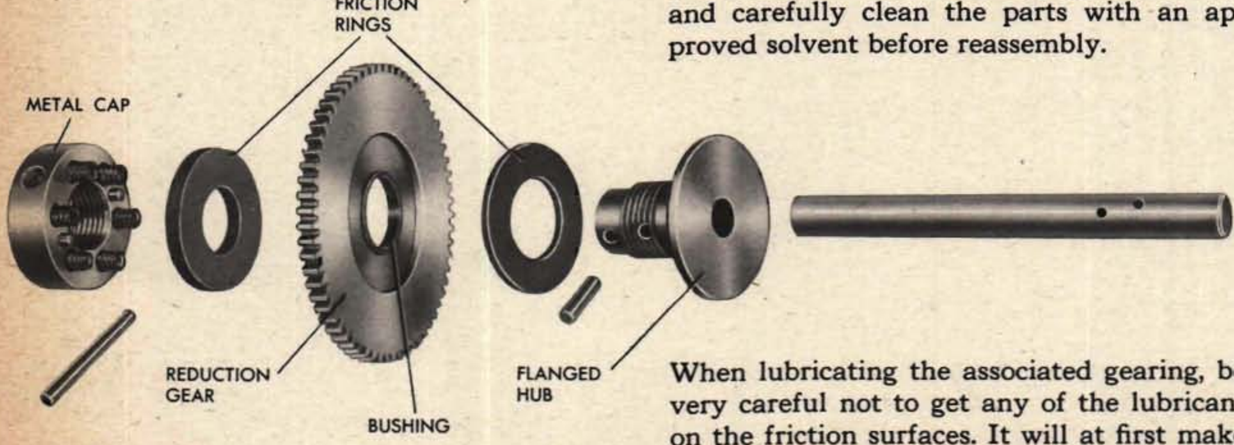


The friction is properly adjusted and its metal cap pinned to the shaft at the time of manufacture. If worn parts are replaced making readjustment necessary, the metal cap must be repinned. As the torque setting varies for different units, consult the assembly drawing for the correct value.



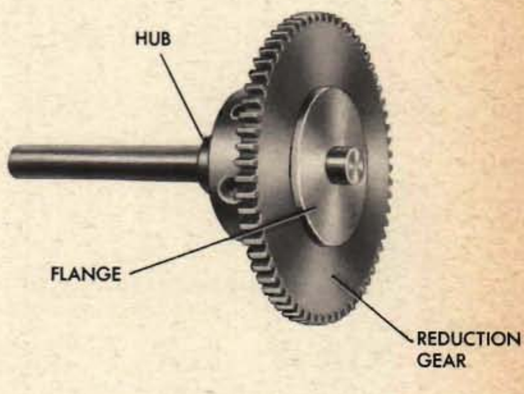
JAMMING OR STICKING of the reduction gear may be caused by dirty or damaged gears or bearings. Jamming or sticking of the friction may be caused by dirty or damaged friction surfaces, a reduction gear frozen to the flanged hub, or improper adjustment of the cap.

Dirty gears or bearings should be cleaned, and damaged ones replaced. The unit must be completely disassembled in order to clean dirty friction surfaces and to repair or replace damaged parts. Use a fine file to remove any roughness on the metal friction surfaces or to remove "glaze" on the non-metal friction surfaces. To insure uniform torque, make sure that the filed parts are of uniform thickness after filing. Remove the filings by air-blowing, and carefully clean the parts with an approved solvent before reassembly.



When lubricating the associated gearing, be very careful not to get any of the lubricant on the friction surfaces. It will at first make the reduction gear slip too freely, but later it will form high spots and make the reduction gear stick intermittently.

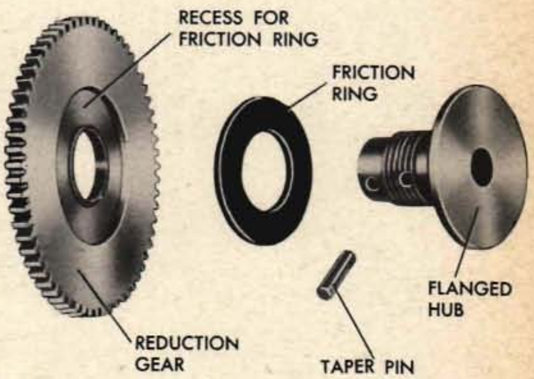
If the reduction gear and bushing are frozen to the flanged hub, disassemble the unit for repair. Use a fine oilstone to remove any nicks on the hub or on the inside surfaces of the gear. Keep trying the gear on the hub until it can be turned freely. Separate and clean the parts. Apply a very thin coating of approved lubricant to the bore of the bushing and reassemble the unit.



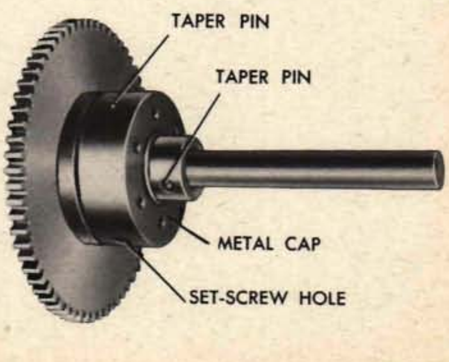
JAMMING of the friction may be caused by improper adjustment of the metal cap. See page 436 for the proper method of adjusting and testing a friction.

Slipping of the reduction gear when the torque on the shaft is normal may be due to a missing taper pin or to improper adjustment of the friction.

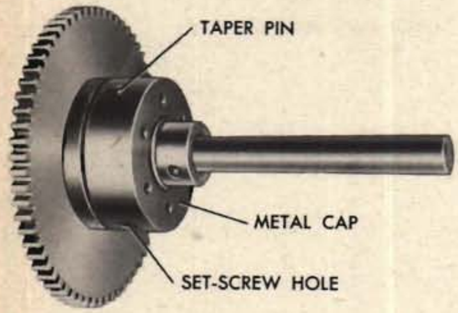
If a taper pin through the metal cap is not staked after reassembly, it may fall out, thereby allowing the metal cap to back off. This would weaken the friction and cause slippage.



Improper adjustment of a friction may result from failure to follow explicitly the directions for measuring torque as given on page 436 under "Adjusting the friction." The string by which the spring balance is attached to the long brass set screw in the metal cap must be kept perpendicular to *both* screw and shaft while measuring the friction torque or a deceptively high reading will be obtained.



Adjusting the friction



If it is suspected that a friction is too tight or too loose because of improper adjustment, the following procedure may be used to test the friction and obtain in inch-ounces the value at which it slips.

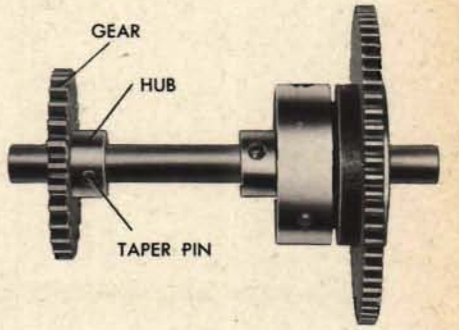
Insert a long brass screw in the set-screw hole of the metal cap. Place the gear in a vise between two wooden blocks, making sure that the vise will not interfere with the rotation of the metal cap. Now attach a spring balance, graduated in ounces, to the brass screw by means of a string. Holding the balance at right angles to both the screw and the shaft, exert sufficient pull to cause the shaft to rotate. As the shaft rotates, the balance must be kept at right angles to the screw and the shaft and the pull maintained as constant as possible. Read the values on the balance at intervals. They should be nearly equal for all points. The average reading in ounces, multiplied by the distance in inches between the center of the shaft and the point where the balance is attached to the screw, gives the torque in inch-ounces.

If the check shows that the torque is not within the limits given on the assembly drawing, the friction must be readjusted. Since readjustment requires that the metal cap be rotated in relation to the flanged hub and shaft, the taper pin will no longer go through all of the parts. To avoid having intersecting pin holes in the shaft, the flanged hub and shaft should be replaced.

To adjust for the proper torque, turn the cap to increase or decrease the friction. The long brass screw can be tightened so that it acts as a set screw while testing the torque and later while drilling and reaming the taper-pin hole. Refer to pages 63-65 for directions on pinning.

Disassembling the unit

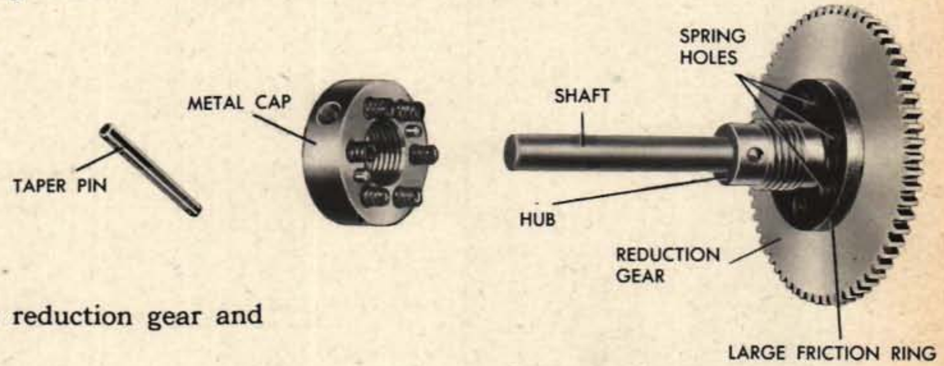
1 Drive the taper pin out of the hub and remove the gear on the end of the shaft.



2 Drive the taper pin out of the metal cap.

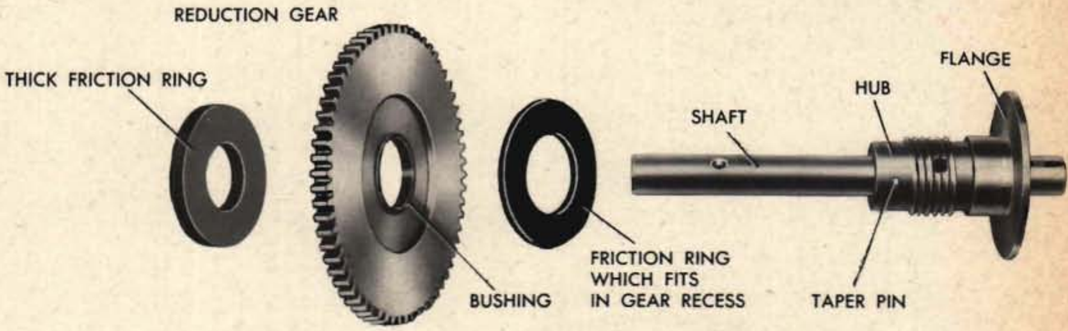
3 Unscrew the cap. The springs will come out with it.

4 Remove the large friction ring from the flanged hub.

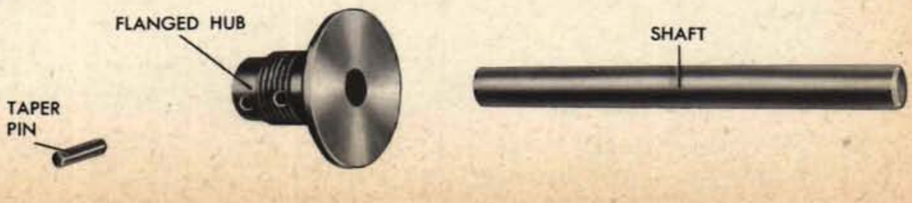


5 Remove the reduction gear and bushing.

6 Take the small friction ring out of the recess in the gear.

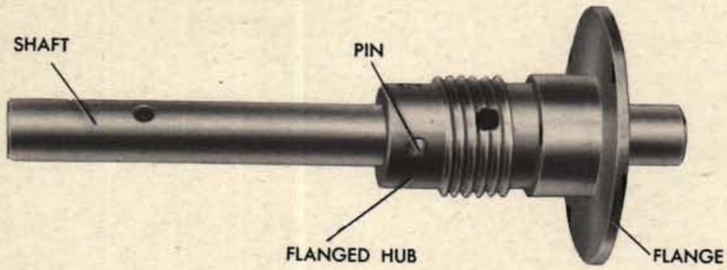


7 Drive the taper pin out of the flanged hub and remove the hub from the shaft.



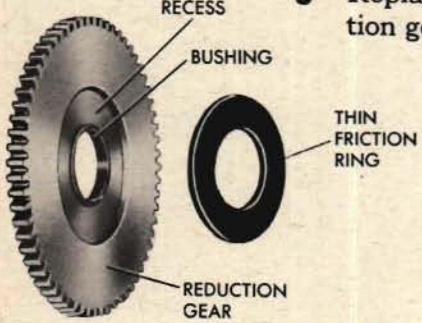
Reassembling the unit

1 After making sure that any burrs on the shaft or hub have been removed by polishing, pin the flanged hub to the shaft.

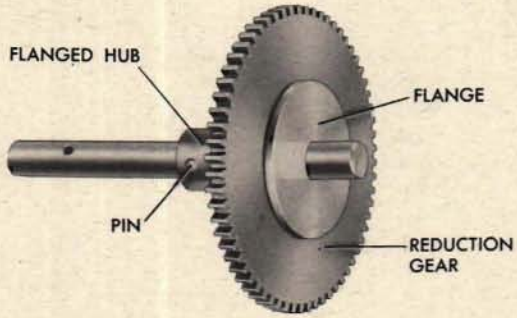


2 Put the bushing in the hole in the gear.

3 Replace the thin friction ring in the recess of the reduction gear.



4 Mount the reduction gear with its recessed surface facing the flange.



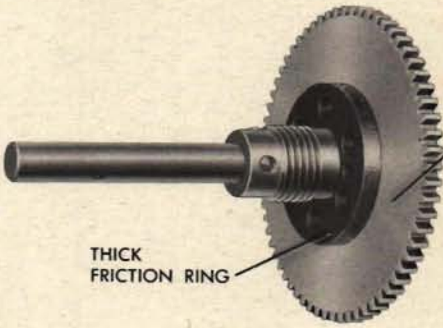
5 Replace the thick friction ring with the spring holes facing away from the gear.

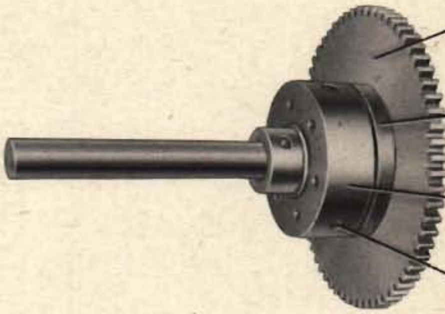
6 Replace the metal cap and springs. Be sure that the springs are properly seated in the cap and that the dowels are properly seated in the holes of the friction ring.

7 If a new flanged hub and shaft are used, adjust the friction to the value specified on the assembly drawing, following the procedure described on page 436. Insert and tighten a set screw in the metal cap.

8 Pin the cap to the shaft with the long taper pin. Remove the set screw.

9 Mount the gear on the other end of the shaft and pin it.



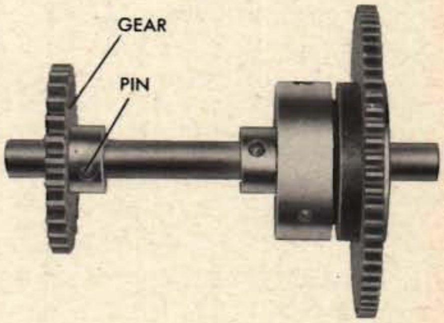


Bench checking the unit

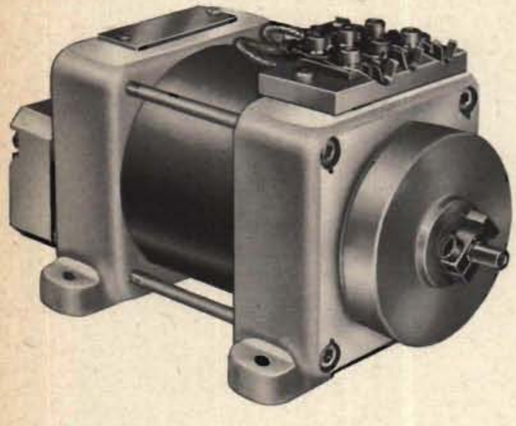
1 The unit should be assembled according to the assembly drawing.

2 The friction must be set for the correct torque. Refer to the assembly drawing for the value.

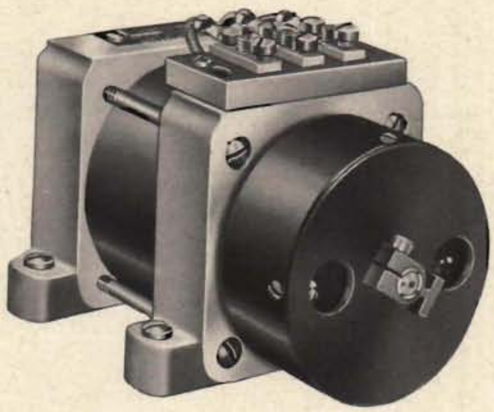
3 When the shaft is held and the gear is turned, the reduction gear should slip smoothly.



DAMPERS



MAGNETIC DAMPER ATTACHED TO SERVO MOTOR SHAFT



MECHANICAL DAMPER ATTACHED TO SERVO MOTOR SHAFT

A damper aids in controlling a follow-up by reducing surges in the shaft line. Dampers enclosed in synchro motors are discussed at the end of the chapter on the synchro motor. The dampers discussed in this chapter are used on servo-motor shaft extensions.

Two types of dampers, magnetic and mechanical, are commonly used with servo motors. Either type can be removed easily by loosening an assembly clamp on the split hub which holds the unit on the servo motor shaft.

The magnetic damper consists of a magnetized rotor enclosed in a case.

The mechanical damper consists of two inertia-type friction brakes enclosed in a case.

A faulty damper may be a cause of follow-up trouble.

Typical symptoms

A faulty damper is usually detected when the follow-up is in operation. Symptoms of trouble which may be caused by both types of damper are discussed in detail in the chapter on the follow-up, page 402. If the trouble indicates a faulty damper, remove the damper and examine it for one or more of the following typical symptoms.

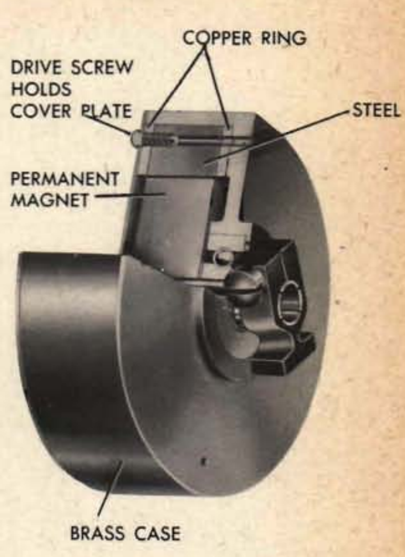
JAMMING: In either unit, the rotor cannot be turned independently of the case.

STICKING: In either unit, the rotor resists turning past certain points. In a mechanical damper the rotor may turn sluggishly.

SLIPPING: In either unit, the rotor turns too freely within the case.

Repairing a magnetic damper

A magnetic damper is a simple unit which usually can be cleaned or remagnetized without disassembly.



Jamming or sticking

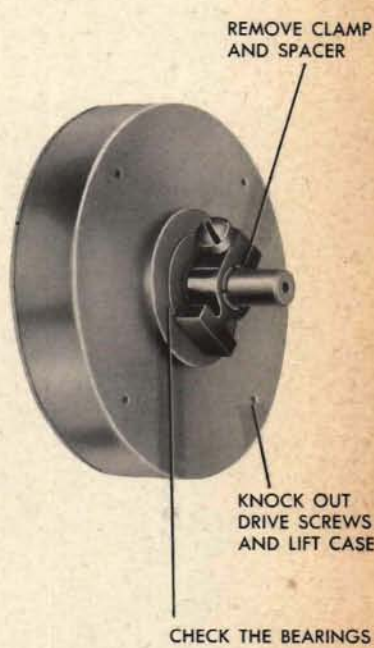
If the rotor and case jam or stick because of dirty bearings, it is possible but not advisable to wash the bearings without disassembling the unit. If this is done, every effort should be made to remove foreign matter which may be washed into the damper case itself. Further, be sure to remove *all* the solvent from the inside of the case before installing the damper. If dirty bearings are not the source of trouble, it is best to replace the unit. As a last resort, if no replacement is available, disassemble the unit to remove a broken rotor, damaged bearings, or foreign material between the rotor and the stator. After reassembly the unit must be remagnetized.

Slipping

If the rotor turns too freely within the case, the damper has lost some of its magnetism. To remagnetize it, place the entire unit in a d-c field generated by 40,000 to 60,000 ampere turns.

Disassembling a magnetic damper

If the unit must be disassembled to clean it or to replace a rotor or a bearing, be careful not to jar it, because magnetic damper rotors are extremely brittle. A cracked or broken rotor cannot be repaired.



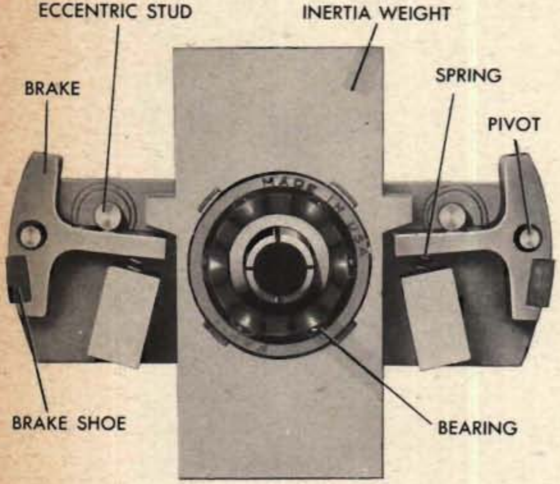
1. Remove the clamp and spacer from the split hub.
2. Knock out the drive screws and lift the case.
3. *If the case has only one bearing,* the snap ring on the split hub must be removed before the rotor can be lifted out. The single bearing is staked in place. It can be cleaned while it is seated in the case. If a new bearing is required, be sure to stake it to hold it in place.
4. *If the case has two bearings,* the rotor and the bearings can be lifted out easily. Tag the spacers so that they may be mounted in their proper relative positions after a bearing has been replaced.

Reassembling a magnetic damper

1. Follow the disassembly procedure in reverse order.
2. After reassembly, magnetize the entire unit in a d-c field generated by 40,000 to 60,000 ampere turns.

Repairing a mechanical damper

Usually a mechanical damper can be adjusted without disassembly, but most of the repair operations require disassembly.



WORKING PARTS OF A MECHANICAL DAMPER

Jamming or sticking

A brake may engage the case continuously or intermittently because of a frozen pivot, a weak or damaged spring, dirty or damaged bearings, foreign matter wedged between the brake and the case, or an improperly adjusted eccentric stud. Disassemble the unit to smooth the pivot, to replace the spring, to clean or replace the bearings, or to remove foreign matter. Bearings staked in place can be cleaned and lubricated with light oil without being unseated.

Slipping

A brake may fail to engage the case because of a frozen pivot, dirty or damaged bearings, or a worn, oily, or damaged brake-shoe surface. Disassemble the unit to smooth a frozen pivot, to clean or replace bearings, or to clean or replace the cork braking surface. To remove oil from cork, clean the surface with a suitable solvent. To mount a new braking surface, cut the cork to size and attach it to the brake shoe according to the method described on page 18.

Adjusting the unit

To adjust a damper, reposition both eccentric studs so that the case will turn freely.

1 Turn one stud so that the case is held by the brake.

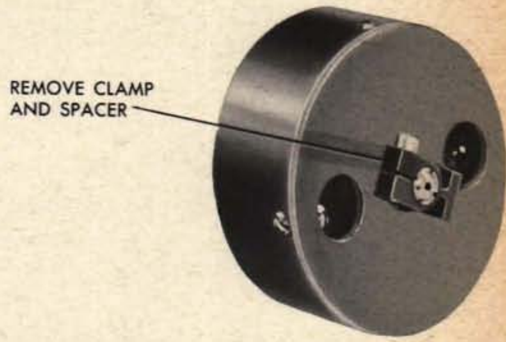
2 Turn the stud in the opposite direction until the brake just releases.

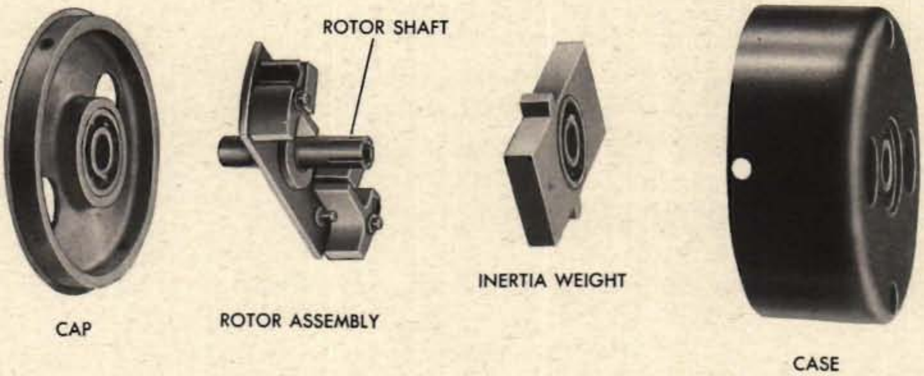
3 Repeat steps 1 and 2 on the other stud and brake.

The brakes should just clear the case when there is a small rotor acceleration, but should hold when the rotor is accelerated rapidly. The eccentric studs should be slip-tight.

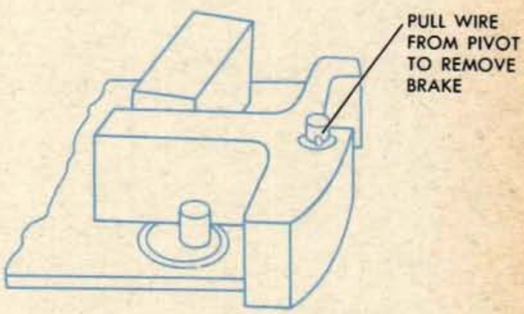
Disassembling a mechanical damper

1. Remove the clamp and the spacer from the split hub.
2. Remove the cap and the spacer.
3. Lift out the rotor assembly, brake mechanisms, and spacer.
4. Pull the inertia weight off the rotor shaft.



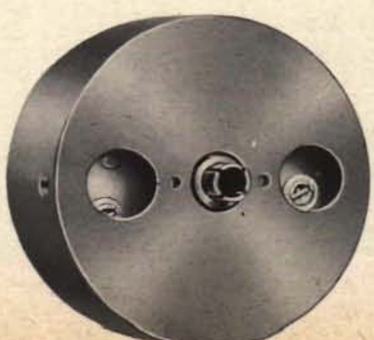


To remove the brake, pull the small copper wire out of the pivot. Staked bearings can be cleaned in place. Replace damaged bearings or springs.



Reassembling a mechanical damper

1. Stake the new bearings.
2. Follow the dissassembly procedure in reverse order.
3. When replacing the cap, line up the two large holes in the cap with the two large holes in the case.



THE SYNCHRO

This chapter is designed to assist the fire controlman in locating and remedying casualties to synchro units. If the fire controlman is not already familiar with the theory of operation, electrical and mechanical characteristics, and general construction of synchro units, he should first read the synchro section of OP 1140. A copy of OP 1303 should also be available as a reference.

Casualties involving "Ship's Wiring"

Synchro system casualties involving "ship's wiring" and the effects of multiple errors in connecting synchro units are thoroughly covered in OP 1303 and will not be repeated here. This chapter will treat the synchro unit rather than the complete synchro system.

Typical symptoms

The more common symptoms of casualties to synchro units are:

Jamming
Sticking
Erratic operation
Overheating

Locating the cause

Jamming

In most cases, jamming occurs after a synchro has overheated. Overheating causes the insulating varnish to decompose. The vaporized products of decomposition condense on the moving parts, causing the rotor to jam.

Jamming of the rotor of a synchro unit can be caused by improper mounting of the unit in its associated equipment.

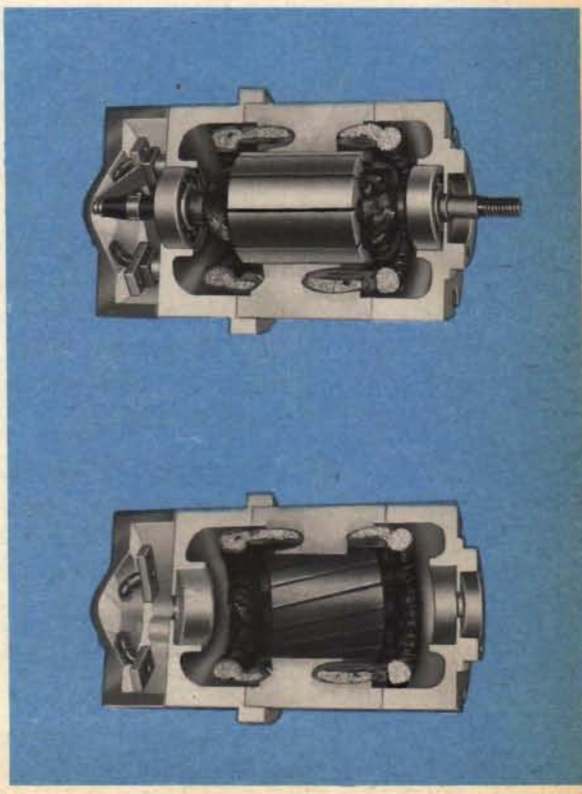
Sticking

Rough operation or sticking is usually caused by dirt, hydraulic fluid, or any foreign substance in the rotor bearings of a synchro motor. If the rotor does not turn freely, check that the rotor end shake is correct. See the assembly drawing for the correct tolerance for any particular unit. Also inspect the rotor bearings as specified in the chapter on *Shaft Lines.*

Erratic operation

Erratic operation is usually due to poor contact between brushes and slip rings. Slip rings should be examined for signs of excessive wear or eccentricity. Brushes making poor contact can be located with an ohmmeter.

CONTROL TRANSFORMER
MARK 5 MOD 3A
TYPE 1CT



Overheating

Excessive current flowing in the rotor or stator coils will cause overheating. Excessive current may result from restraint of a motor rotor, open rotor circuits in another connected synchro or in the external "ship's wiring," or improperly connected external wiring. For instructions on locating such troubles, refer to the trouble-shooting section of OP 1303.

Disassembling the unit

Most synchro units are disassembled in the same general manner. The disassembly of several representative units is evident from the accompanying exploded illustrations; however, there are certain precautions that should be observed.

Care must be taken at all times to keep the various parts of the synchro clean, especially the bearings, brushes, and slip rings. On the larger units, care must be taken to avoid bending the brush supports when removing the rotor from the stator. In the case of those units that are equipped with the shoe-type, silver graphalloy brushes, the brush rigging should be removed from the unit before the rotor is removed.

Repairing the damaged part

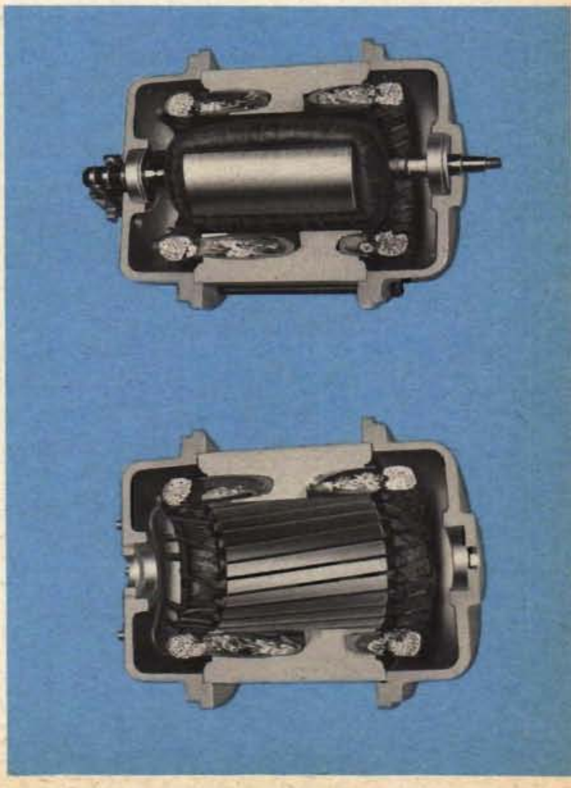
If a synchro requires major repairs, it is recommended that it be replaced. Since all Mods of a given size and type synchro are in most cases interchangeable, a check of the spare parts for all ordnance equipments should be made before attempting to make synchro repairs. However, if no spares are available, and the operational demands of the ship require that the synchro function, emergency repairs will have to be made. A synchro unit which has undergone major shipboard repairs should be replaced at the first opportunity.

If the insulating material has broken down enough to cause "shorts" in either the rotor or the stator, the defective part will have to be wholly or partially rewound. The size and number of turns of wire required may be obtained by examination of the damaged part.

Dirty bearings, burred or bent shafts, and similar mechanical casualties should be reworked in accordance with the instructions in the chapter on *Shaft Lines.*

Rough spots on slip rings should be smoothed with fine crocus cloth or French paper. The slip rings should not be burnished because this causes high and low spots which interfere with the brush contact at high speeds.

SYNCHRO GENERATOR
MARK 3 MOD 3
TYPE 7G



The rotor end shake in the Mod 3 units is adjusted by varying the size of a spacer. Since the location of this spacer is different for each frame size, reference should be made to the pertinent assembly drawing.

Thorough cleaning usually will eliminate sticking of dampers. If it becomes necessary to replace the damper bearing, care should be taken to see that it turns freely after it has been staked into the damper flywheel.

Reassembling the unit

In general, the procedure for reassembling synchro units is the reverse of disassembly. Sufficient information can be obtained from the exploded illustrations. However, certain precautions should be observed. Make sure that the bearing at the slip-ring end of the rotor is positioned so that it will counteract thrust towards the slip-ring end of the rotor. Make sure that all motor rotor bearings are clean and turn freely. The slightest stick in a motor rotor bearing will cause an error in the rotor position because there is very little torque on the rotor when it is nearly in agreement with the signal from the transmitter. Make sure that all snap rings are properly seated so that they will not become loose when subjected to vibrations. When installing a synchro end cap, tighten the holding screws evenly. On synchros having shoe-type graphalloy brushes, the brush rigging should not be installed until the rotor is in place. Lubricating instructions for synchro units are contained in OP 1303.

Bench checking the unit

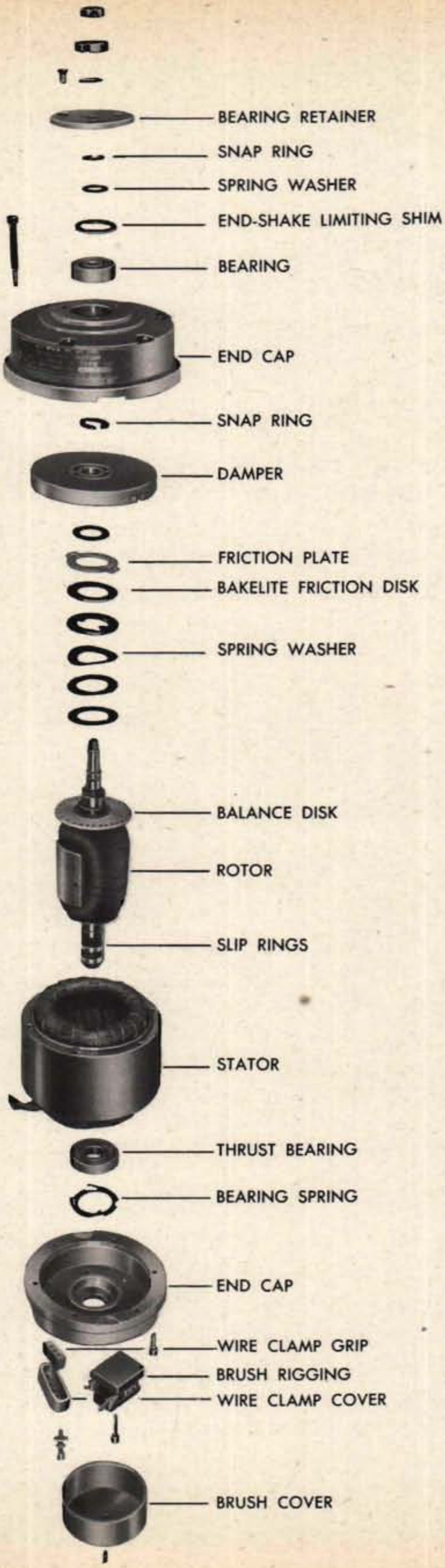
With an ohmmeter:

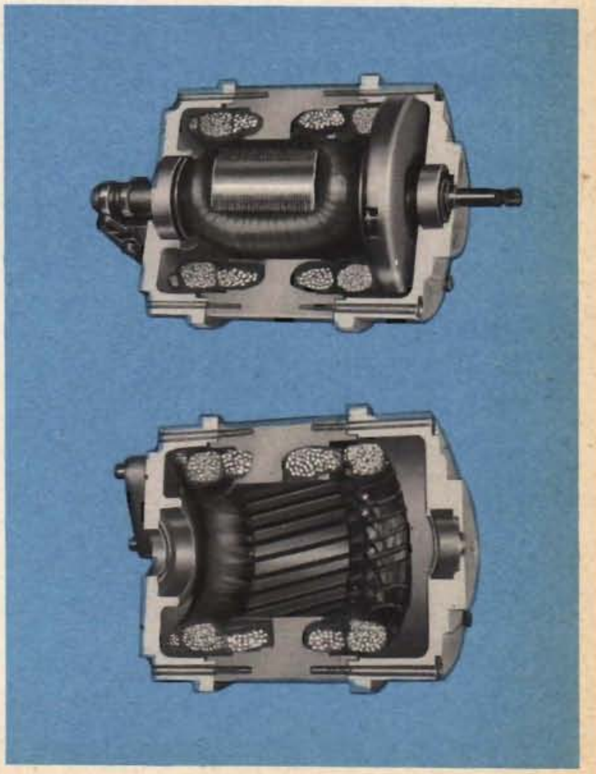
1 Check the d-c resistances between S1–S2, S1–S3, and S2–S3 pairs of terminals. They should be equal to each other and approximately equal to the value given in the characteristics section of OP 1303.

2 Check the d-c resistance of the rotor winding. It should be approximately equal to the value given in OP 1303. Check to see that this value does not vary as the rotor is turned slowly.

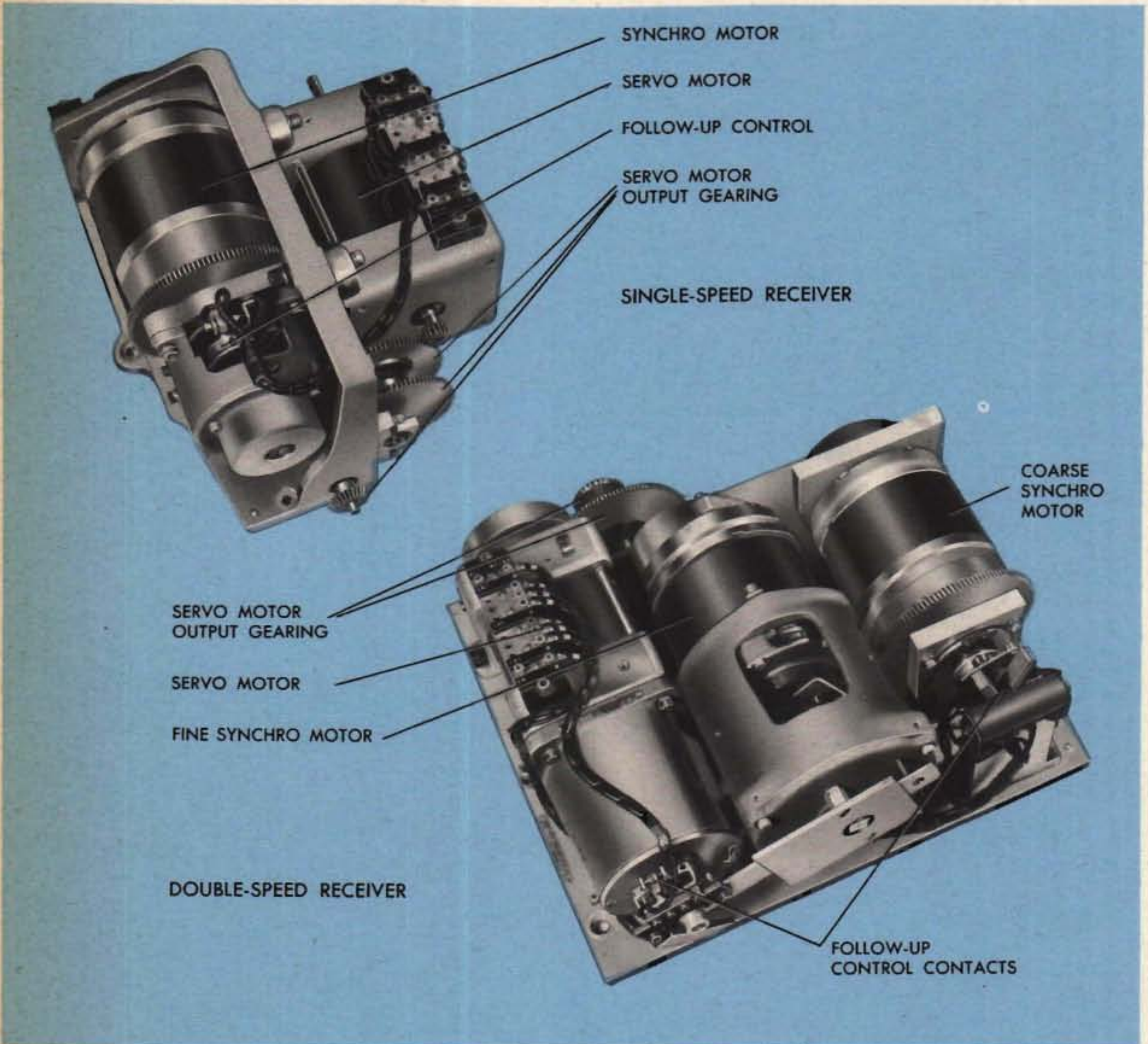
If the unit being tested is a synchro motor, connect it to a generator and make sure that it follows movements of the generator smoothly. De-energize the motor and displace the rotor approximately 179 degrees. When the motor is energized, it should come into synchronism with the generator without oscillating excessively.

SYNCHRO MOTOR
MARK 4 MOD 3
TYPE 5F





SYNCHRO RECEIVERS



A synchro receiver combines a follow-up with one or two synchro motors so that synchro signals of low torque are amplified by the servo motor to drive heavily loaded shafts.

Indicating synchro receivers, which are made up of synchro motors and dial assemblies, are not considered as basic mechanisms in themselves. See *The Synchro,* page 444, and *Dial Assemblies and Counters,* page 136.

This chapter is concerned only with single-speed and double-speed *automatic* synchro receivers.

A single-speed receiver may be used to register either large changes with low accuracy or small changes with great accuracy. A double-speed receiver can accurately register both large and small changes.

A single-speed receiver consists of a bearing-mounted synchro motor, a follow-up control, and a servo motor. These three units, mounted on a frame and connected by shaft lines, make up the unit.

A double-speed receiver consists of two synchro motors, one fine and one coarse, a follow-up control, and a servo motor. These units, mounted on a plate and connected by shaft lines, make up the unit.

The synchro motors receive the electrical input signal. The follow-up control switches the signal from the synchros to the servo motor. The servo motor amplifies the signal and drives the output gearing in response to the input signal.

In several types of receivers, the details of follow-up control design and the arrangement of units differ from those described and illustrated in this chapter. In general, however, directions given here can be applied to all the other receivers except range receivers. Since the construction of range-receiver contacts may be different for each unit, range receivers are described in the various instrument OP's.

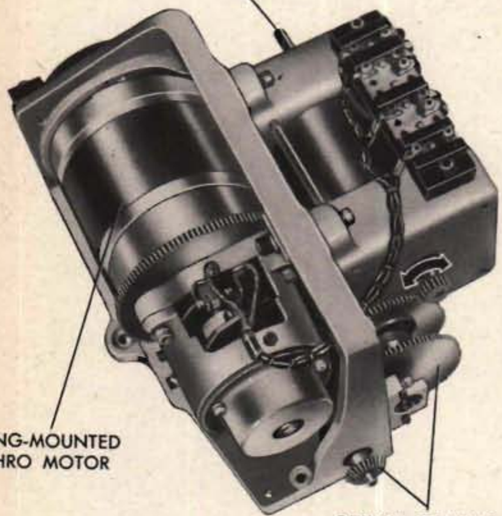
If the operation of a receiver is known to be faulty, first clean the parts as well as possible and inspect the unit. The decision to repair the unit in place or to remove it from the instrument depends on the location of the unit within the instrument and whether the difficulty is of minor or major importance.

The typical symptoms and the procedure for locating the cause are similar for both single- and double-speed receivers.

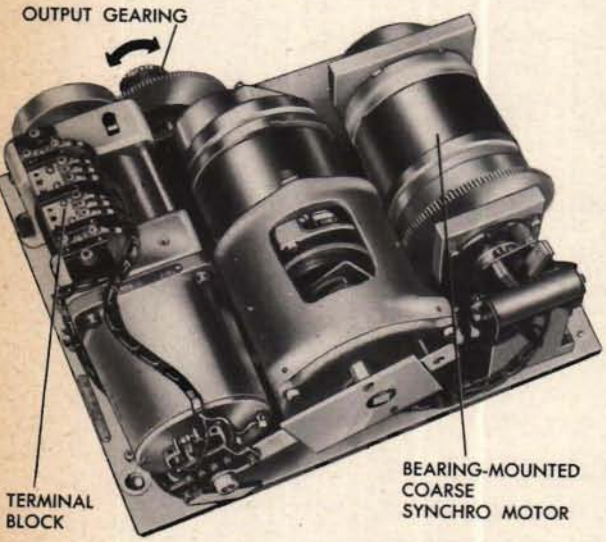
Typical symptoms

If a test analysis and unit check test indicate that the servo motor in a synchro receiver does not follow the synchro input signal normally, look for one or more of the following typical symptoms:

FAILURE TO RUN: The output does not turn.
RUNNING AWAY or DRIFTING: The servo motor runs constantly or drifts off from a synchronization point.
ERRATIC OPERATION: The output may be rough or sluggish, may jiggle, hunt, follow in only one direction, or synchronize at more than one point for a fixed synchro input signal. The double-speed unit may also buck.
NOISE and HEAT: The unit operates noisily or is overheated.



SINGLE-SPEED RECEIVER



DOUBLE-SPEED RECEIVER

Locating the cause

Failure to run

If the servo motor does not turn, the servo output does not follow the synchro input signal, or the receiver synchronizes or tends to synchronize at only one point, the trouble may be:

Jammed gearing
Dead servo motor
Slipping parts
Locked synchro rotor

Jammed gearing

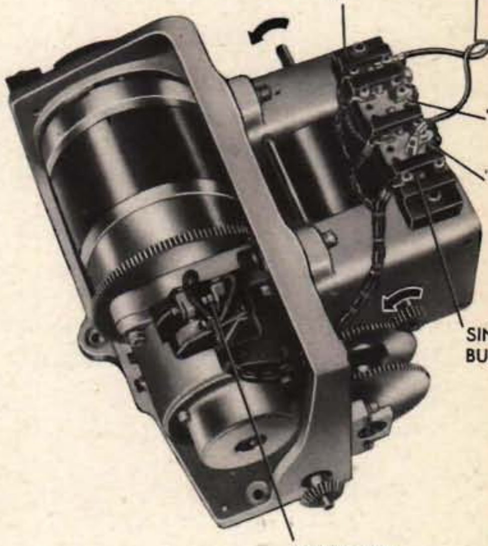
With the power OFF, try to turn the output gearing by hand. Inspect the unit for dirty or damaged gears and bearings, and for foreign material or interference between moving parts. If the rotor of the servo motor is jammed, the servo must be repaired or replaced. For directions on repairing a servo motor, refer to page 426.

The synchro of the single-speed unit and the coarse synchro of the double-speed unit, which are bearing-mounted, are also part of the shaft line.

Dead servo motor

A servo motor may not operate because of an open circuit in the receiver wiring or because the servo motor or the capacitor has become defective.

BY-PASS TEST

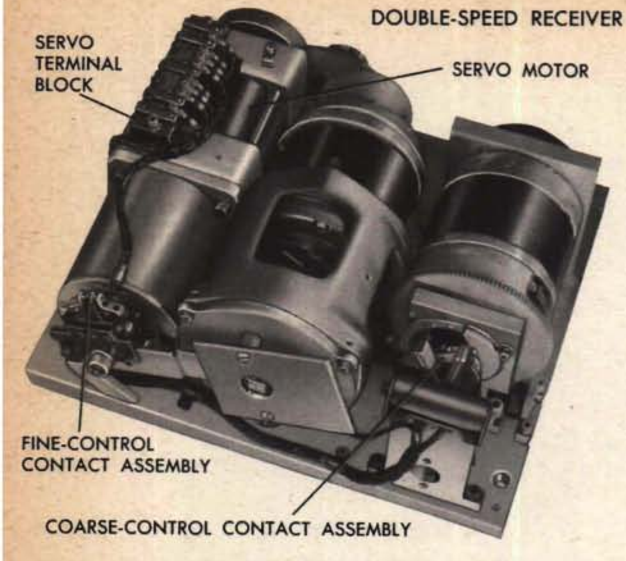


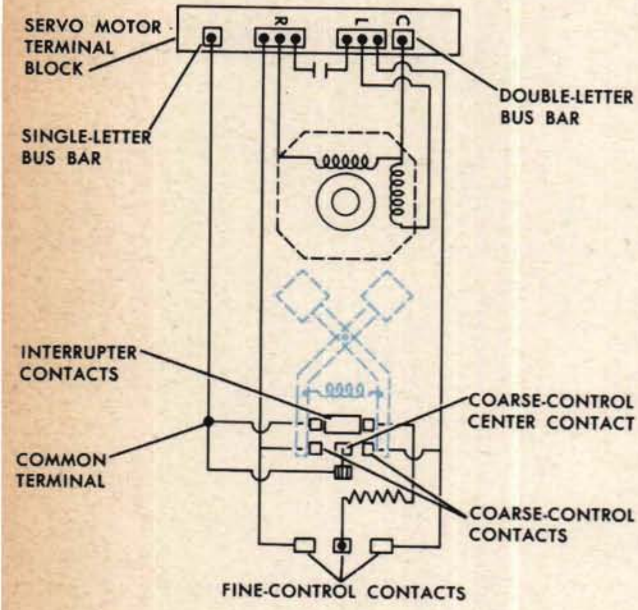
If the motor does not operate when the follow-up contacts are displaced, make a by-pass test to check whether the trouble is in the servo and capacitor or in the receiver circuits. To do this, remove the power lead from the single-lettered bus bar on the terminal block. Touch this lead to the bus bar marked "R" or "L." This should cause the motor to run. *Do not touch the terminal marked "C,"* or a short circuit will result.

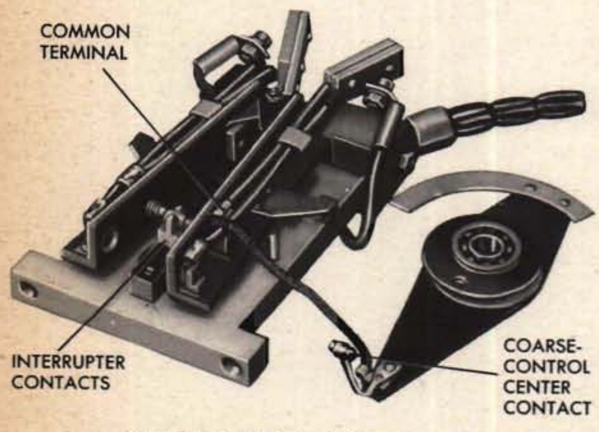
If the motor runs when the single-letter lead is touched to L or R, the trouble is probably due to either an open in the receiver pigtail wiring or dirty or damaged contacts. Replace faulty pigtails and terminals lugs. Contacts which are not badly worn may be removed and resurfaced. Burned or deeply pitted contacts should be replaced.

If the motor does not run under the by-pass test, the trouble may be one of three things: a faulty capacitor, an open or short within the servo stator, or a short between the R and L stator circuits.

Check for a faulty capacitor by trying a new one. To check for a defective servo motor or a short between the R and L stator circuits, remove pigtail terminals 1 and 2 from the motor terminal block and repeat the by-pass test. If the motor now runs under this by-pass test, there is probably a short across the R and L leads caused by defective pigtail wiring or by the contacts being too close together. If the motor still does not run, the trouble must be in the motor itself. For instructions on repairing the servo motor, see page 426.







COARSE-CONTROL CONTACT ASSEMBLY

Determine whether the servo motor of the double-speed receiver will operate in fine control by offsetting the fine-control contacts, and in coarse control by offsetting the coarse-control contacts.

If the servo does not operate in either fine or coarse control, the trouble is probably due to an open circuit between the servo terminal block and the common terminal.

If the servo will not operate in coarse control but operates in fine control when the interrupter contacts are closed, the trouble may be an open circuit between the common terminal and the coarse center contact.

If the servo will not operate in fine control but operates in coarse control, there is probably an open circuit between the interrupter contact and the fine center contact.

An open circuit may be caused by a loose connection or a broken wire and can often be repaired in place.

Slipping parts

If the servo motor turns but the output does not follow the input signal, the trouble may be caused by a loose friction relief, an unpinned gear, or a loose clamp. Instructions for the repair of frictions are given on page 434. The assembly drawing gives data for setting the frictions. An unpinned gear may usually be repinned in place.

Locked synchro rotor

If a single-speed receiver remains synchronized at one point only or a double-speed receiver synchronizes or tends to synchronize at one point only, the trouble may be caused by a locked synchro rotor.

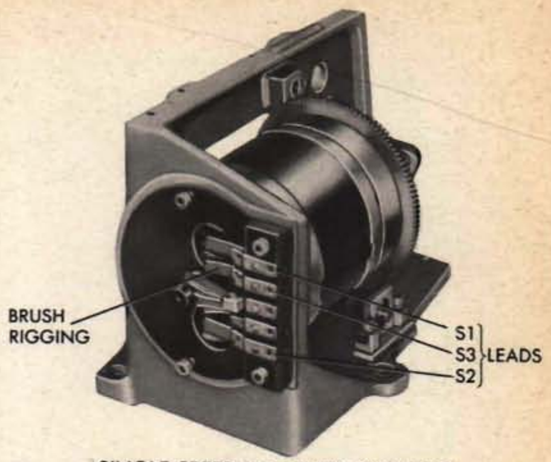
On the double-speed receiver, locking may also be accompanied by bucking. Refer to page 459.

If the rotor is free to turn when the synchro power is OFF and is locked when a varying input is applied with the power ON, the trouble may be caused by a short circuit between the S leads. Check the external electrical connections to the synchro.

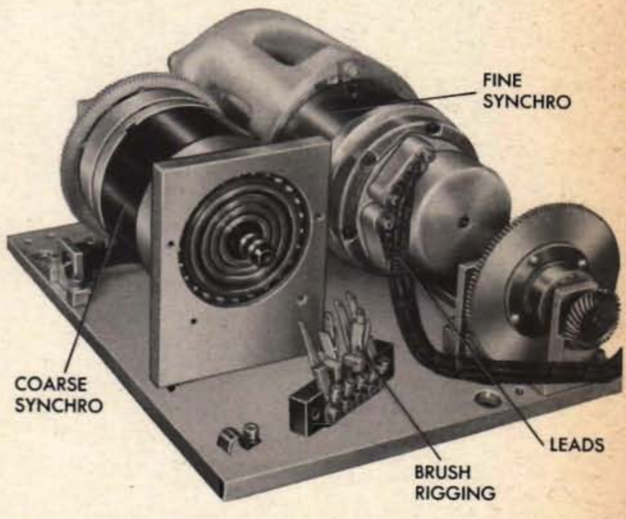
On the single-speed unit, look for damaged brush rigging or foreign objects which may be short-circuiting the leads.

On the double-speed unit, look for damaged brush rigging in the coarse synchro and bare leads on the fine synchro. If a fine synchro lead is broken, replace the synchro if possible. Otherwise splice the lead and wrap the splice with insulating tape.

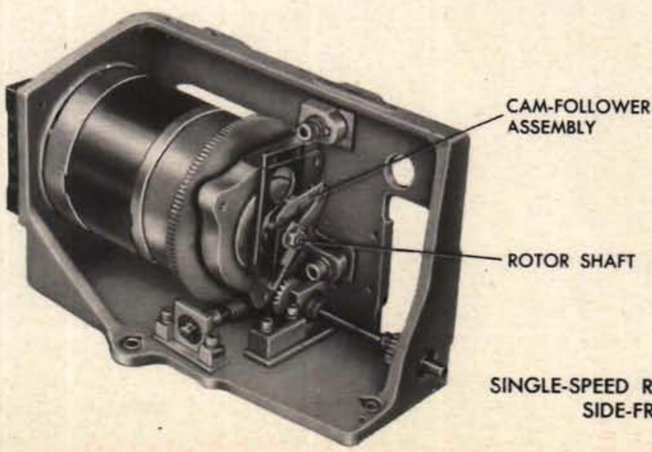
If the rotor is locked when the synchro power is OFF, the trouble may be caused by mechanical jamming of the rotor. Dirty or damaged bearings, a burned-out synchro, interference with the cam-follower assembly, or a bent part may be the cause.



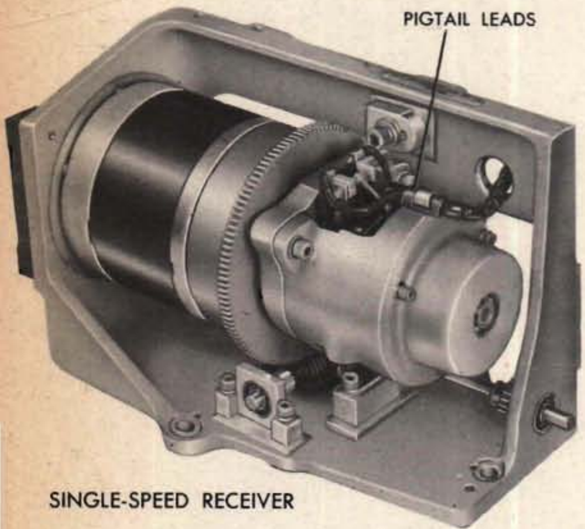
SINGLE-SPEED RECEIVER SYNCHRO
REAR VIEW



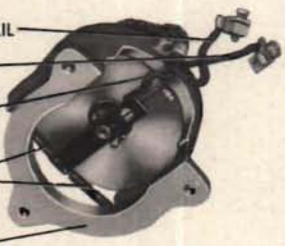
DOUBLE-SPEED RECEIVER SYNCHROS
REAR VIEW

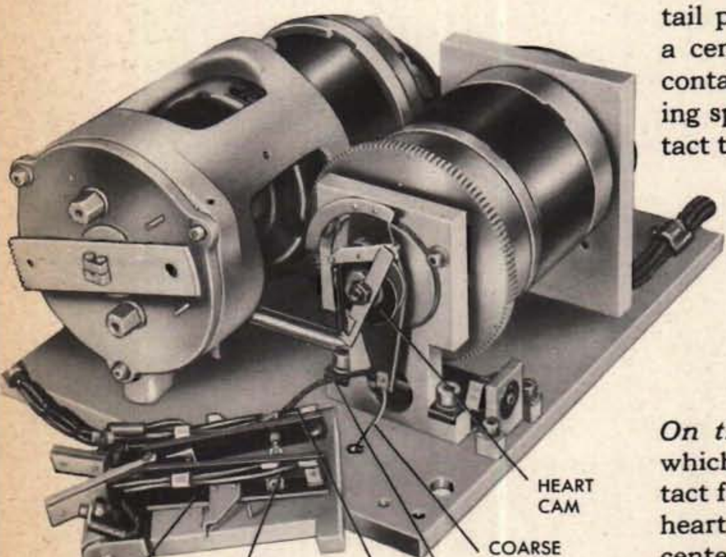


SINGLE-SPEED RECEIVER SYNCHROS
SIDE-FRONT VIEW



SINGLE-SPEED RECEIVER





DOUBLE-SPEED RECEIVER SYNCHROS

Runaway output

If the servo motor turns constantly in one direction regardless of the synchro input signal, the trouble may be caused by a short circuit between the center pigtail and either the right or left-hand pigtail in a single-speed unit, or between the center pigtail and right or left-hand pigtail of the coarse control in a double-speed unit.

The same type of short circuit in the fine control of the double-speed unit would result in bucking. See page 459.

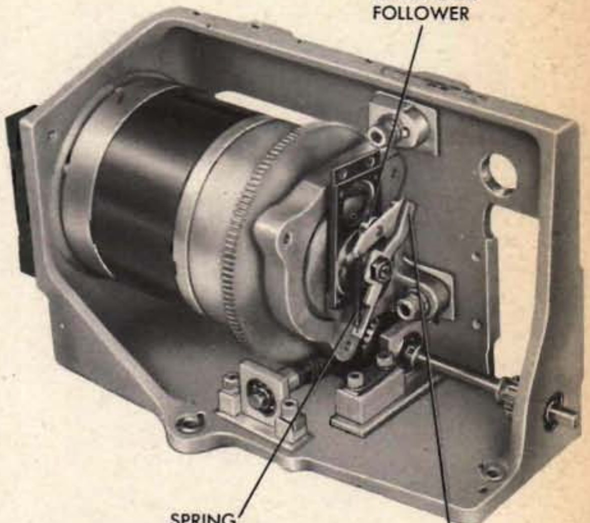
On the single-speed unit, look for a tight pigtail pulling the outside contacts to one side, a center contact jammed under an outside contact, a short circuit, or a missing centering spring which may permit the center contact to be pulled over to one side.

On the double-speed unit, look for causes which would prevent the coarse center contact from responding to the movement of the heart cam. Check to be sure that neither the center contact nor the center-arm pigtail is jammed in the scissor-arm assembly. Check also to be sure that the center-arm pigtail is not short-circuited with the left or right-hand pigtail or contacts.

Drifting output

If the output of a single-speed unit creeps slowly, regardless of the input signal, check the synchro rotor torque. If there is normal torque, the trouble may be caused by a jammed pivot or a missing spring on the heart-cam follower.

If there is no torque, there is probably a broken connection between the terminal buses and synchro motor windings caused by broken, bent, or dirty slip rings or brushes.

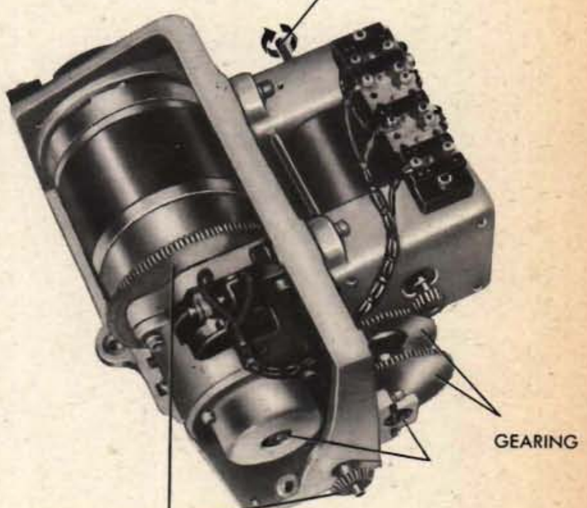


SINGLE-SPEED RECEIVER SYNCHRO

Erratic operation

If the servo output does not follow the input signal normally, the trouble may be described as:

Rough output: Output does not follow signal smoothly.
Bucking: Fine and coarse contacts of double-speed unit oppose each other and cause the servo to drift in one direction and then drive back in the other direction.
Hunting: High-amplitude, low-frequency shaft oscillation.
Jiggling: Low-amplitude, high-frequency shaft oscillation.
Sluggishness: Servo output is too low.
Faulty synchronization: Receiver synchronizes at more than one point for a fixed input signal.

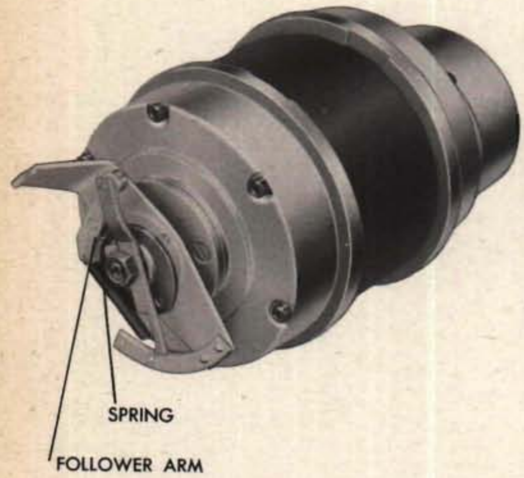


SINGLE-SPEED RECEIVER

Rough output

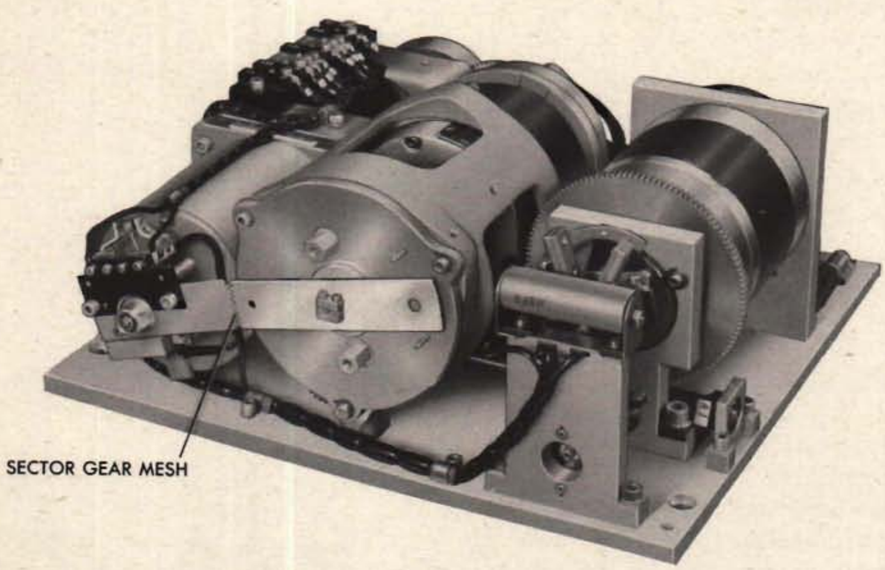
A rough output may be caused by mechanical trouble in the shafting and gearing of the unit, or by mechanical or electrical trouble in a follow-up control or synchro.

With the power OFF, turn the shafts by hand and check for bent shafts and dirty or damaged bearings and gear teeth.



Check the follow-up control thoroughly. Look for jamming or sticking in the follow-up control assembly or dirty or damaged contacts and bearings.

Sticky synchro bearings may cause the output to be rough. To check synchro bearings for sticking, disconnect the rotor shaft from the follow-up control and turn the rotor by hand, with the power **OFF**. The simplest way of doing this is to remove the spring from the heart-cam follower and move the rotor by means of the follower arm.



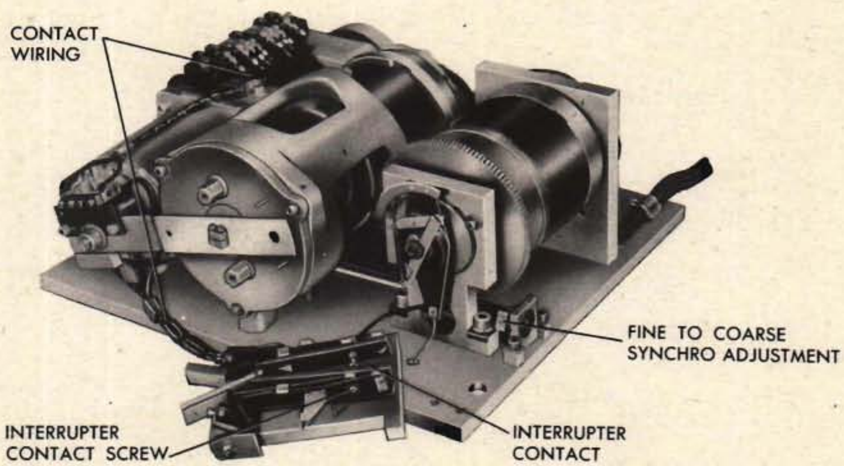
On the double-speed unit, look also for a dirty, damaged, or sticking sector gear mesh; interference with the sector arms or with the linking arm between the fine heart cam and the jewel differential; and incorrectly aligned or loose interrupter contacts or fine contacts. Sticking or binding in the jewel differential will also cause the receiver output to be rough. See the chapter *The Jewel Differential,* page 182, for the method of checking.

Bucking

Bucking occurs only in double-speed units. It results when the signals transmitted through the fine and coarse contacts oppose each other and cause the servo motor to drift off in one direction and then drive back rapidly in the other without synchronizing. When bucking occurs, it will be noted that the follower rollers are not in their respective heart-cam detents simultaneously.

Bucking may be caused by an improper adjustment between the synchro motors, improperly adjusted interrupter contacts, reversed rotation of a synchro rotor, incorrectly connected contact wiring, or by an open synchro stator lead.

In making a test for bucking, use a transmitter which has properly adjusted fine and coarse generators geared together in the same ratio as the receiver synchro motor. Connect the transmitter to the receiver and transmit a fixed signal. Energize the servo motor so that the receiver will attempt to synchronize. Note whether the receiver is unstable or bucks and observe the heart-cam followers. Repeat the test for different fixed signals because certain types of bucking do not occur at all synchro rotor positions. Turning the power OFF while the signal is being changed for each test will further aid in locating a position where the receiver bucks.



If the test shows that the receiver bucks, first determine whether improper adjustment between the fine and coarse synchros is causing the fine and coarse contacts to oppose each other. If the interrupter contacts have been screwed in too far, the follower of the fine heart cam will drive beyond the peak before the coarse-control center contact can open the scissor arms, break the interrupter contacts, and take control. This action also causes the fine contacts to oppose the coarse contacts. To adjust the fine and coarse synchros and the interrupter contacts, refer to pages 488-489.

To check for proper synchro rotation, de-energize the servo motor and transmit an increasing signal. Use the wiring diagram to check whether the rotors turn in the proper direction. If they do not, check the wiring to determine where the reversal has been introduced, and make the necessary corrections.

If bucking is due to an open synchro stator lead, it will be noticed that synchro rotor torque and direction of rotation vary during a revolution. Refer to the wiring diagram while checking the stator leads and connections.

To check for reversed servo contact wiring in the follow-up control, move the center contact to complete the circuit for an increasing signal and observe whether the motor shaft turns in the direction indicated by the wiring diagram.

Hunting

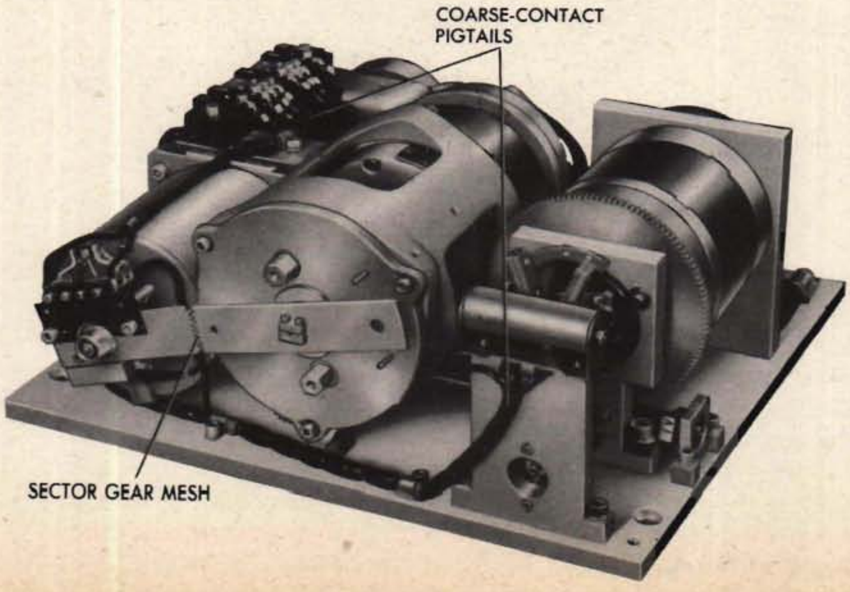
FINE

A receiver is hunting when, instead of synchronizing, it continues to drive back and forth through the synchronization point.

In the double-speed receiver, hunting may be caused by a reversal of the coarse-contact pigtails. This causes the receiver to hunt because the follower tries to position itself at the peak of the heart cam instead of in the detent. A tight sector gear mesh may also cause the double-speed receiver to hunt.

COARSE

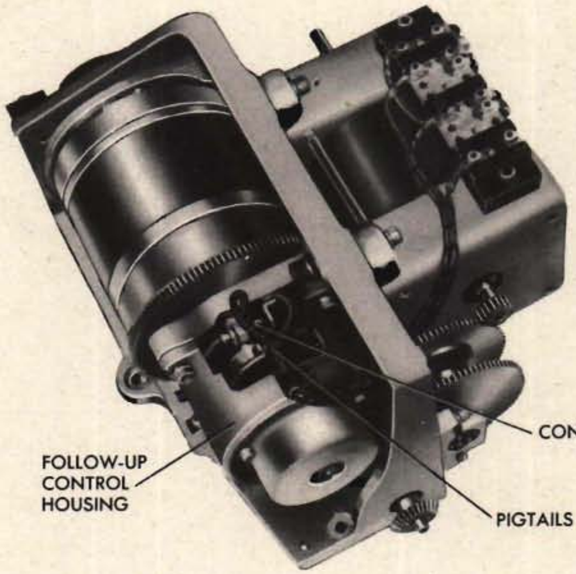
In the single-speed receiver, hunting may be caused by reversed contact wiring.



Jiggling

Jiggling is a series of low-amplitude, high-frequency oscillations of the output shaft which may occur when the input signal is not changing.

It may be caused by too closely spaced contacts, loose contacts or pigtail terminals, tight or stiff pigtails, or a faulty servo damper. A loose clamp connecting the center contact arm to the magnetic-drag rotor or a weak magnetic drag will also cause jiggling in the single-speed receiver.



Sluggishness

In turning to synchronize with the input signal, a servo may operate too slowly because of dirty contacts or a defective capacitor.

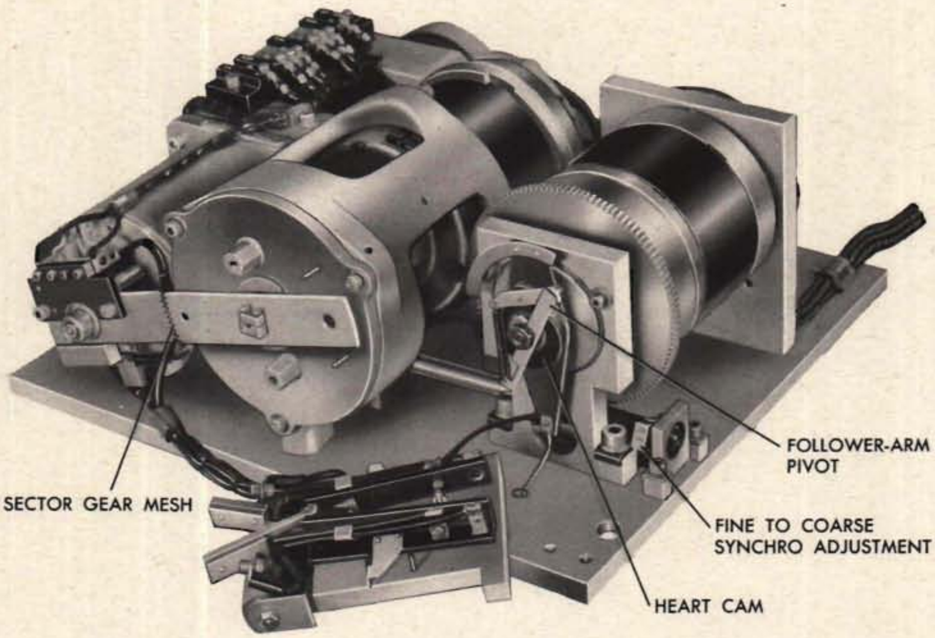
The contacts may be cleaned or the capacitor replaced and an operation test made while the receiver is still in the instrument.

CAUTION

Certain receivers are designed to lag behind the incoming signal an amount proportional to the rate of change of the signal. Operation in these receivers should not be confused with operation due to the above-mentioned casualties. If there is any doubt about the slowness of the receiver, the strength of the magnetic drag and of the contact centering springs should be checked against the assembly drawing.

Faulty synchronization

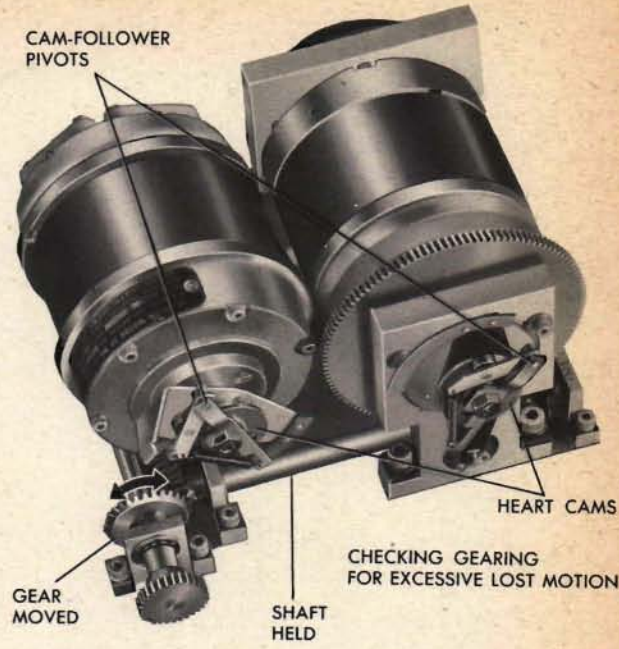
With a fixed input signal, a receiver may have either a poorly defined synchronization point or two separate synchronization points.



A poorly defined synchronization point may be caused by dirt or foreign material in the detent of the heart cam, by a jammed cam-follower pivot, by a tight sector gear mesh, by slipping or excessive lost motion in the follow-up control gearing, or by an open in a synchro stator circuit.

Synchronization at two separate points for a fixed input signal may be due to an open synchro rotor circuit or to a nick or piece of foreign material on the working surface of a heart cam. Improper adjustment between the coarse and fine synchros may cause the receiver to appear to synchronize at two points, but this will usually be accompanied by bucking.

Before removing the unit for repair, make the check tests as directed in the instrument OP's in order to eliminate the possibility of an open connection outside the unit or even outside the instrument.

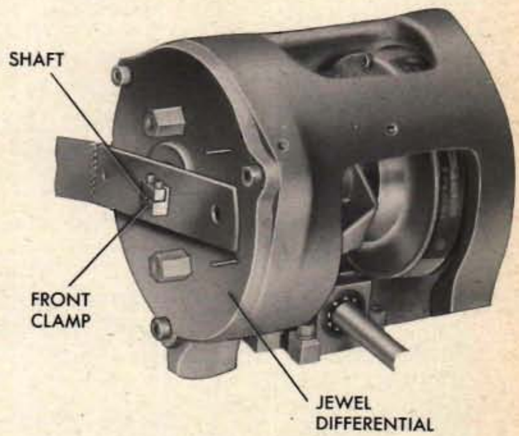


DOUBLE-SPEED RECEIVER SYNCHROS

Jamming or sticking of the cam-follower pivot or the sector gear mesh, dirt or nicks on the heart cam, or excessive lost motion or slipping of the follow-up control gearing may prevent perfect mechanical transmission of the synchro rotor position to the heart cam or contact assemblies.

Partial disassembly may be necessary in order to free a jammed or sticking pivot, but defects in the gearing or in the heart cams can often be eliminated without removing the unit from the instrument.

In the double-speed receiver, check to be sure that the sector clamps are tightened securely on the flat sides of the jewel differential shafts.

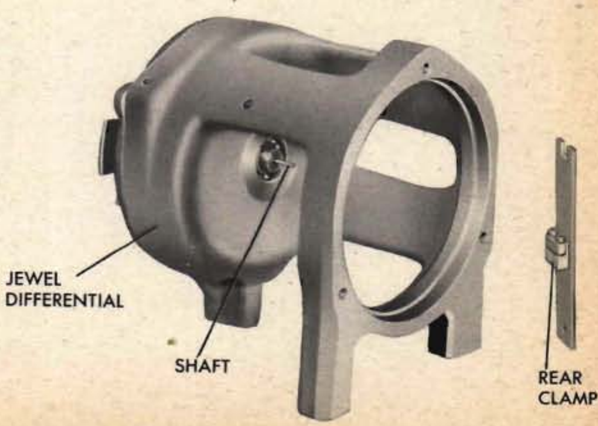


Noise and heat

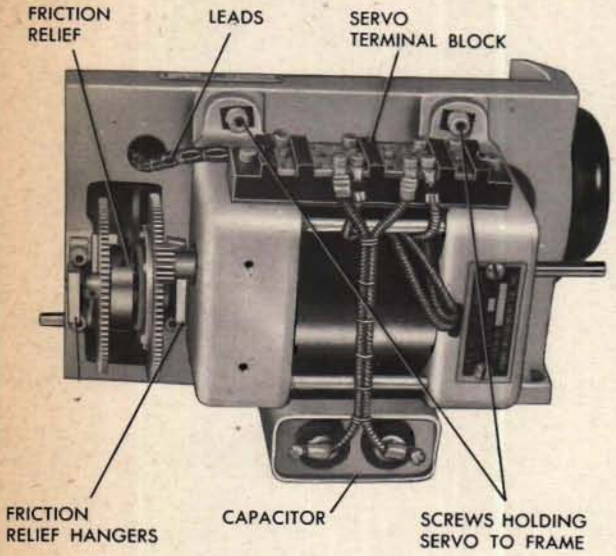
Noise may result from sticking or damaged gear teeth. This symptom usually occurs together with other symptoms such as roughness or a locked synchro rotor.

Excessive heat or a burned-out motor is usually caused by an open or a short circuit or a mechanical overload of the rotor. A current of higher amperage than the unit is designed to take then flows through the coils and generates sufficient heat to destroy the insulation and ruin the motor.

Before testing a receiver in which a burned-out synchro has just been replaced, check for open or short circuits in the receiver synchro wiring, and for mechanical causes of rotor overloading. Otherwise the new motor may burn out during the test.



Disassembling the single-speed unit



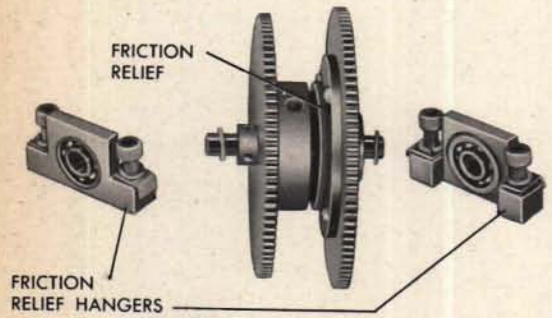
1 Remove the leads from the terminal block of the servo.

2 Remove the screws holding the servo and capacitor to the frame.

3 Lift out the servo and capacitor.

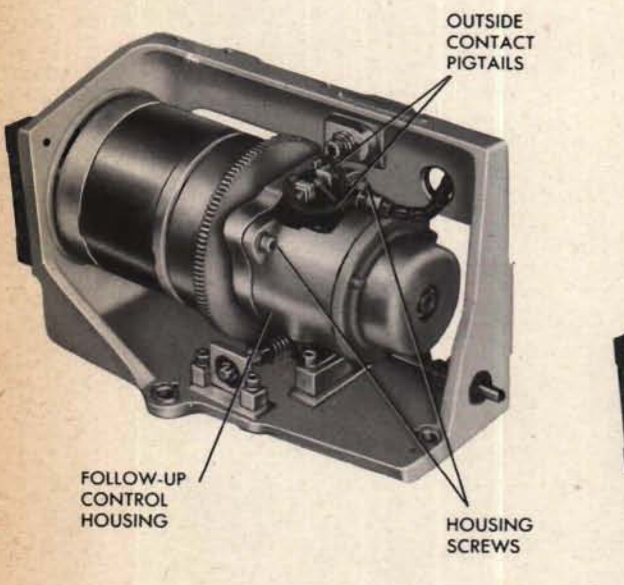
For instructions on the disassembly and repair of the servo motor, refer to page 426.

For instructions on checking the capacitor, refer to page 430.



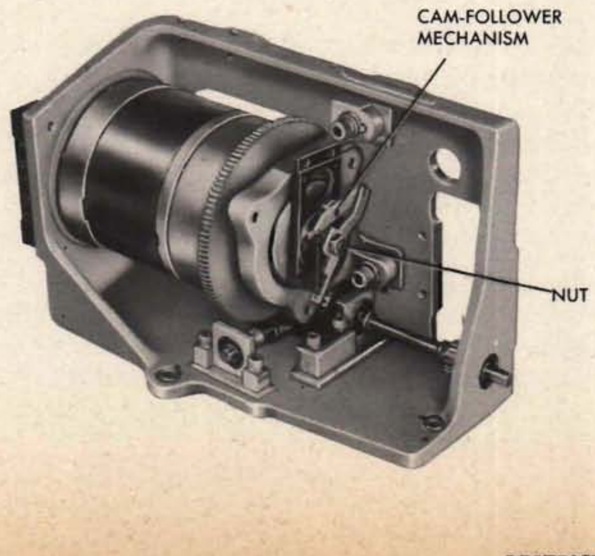
4 Remove the hangers and the friction relief.

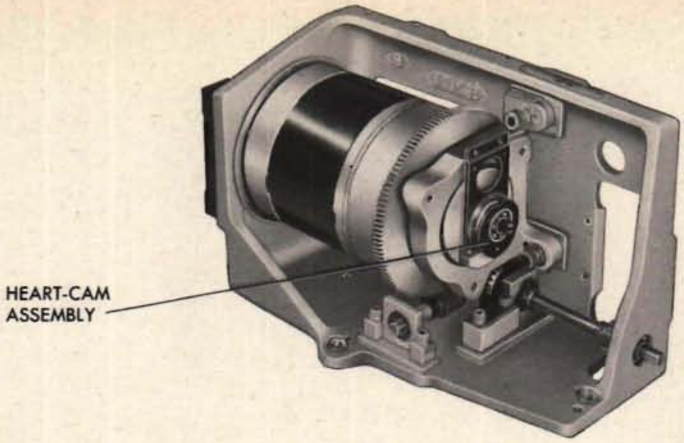
5 Disconnect the outside contact pigtails. Tag them.



6 Remove the follow-up control housing.

7 Remove the cam-follower mechanism by unscrewing the rotor nut.



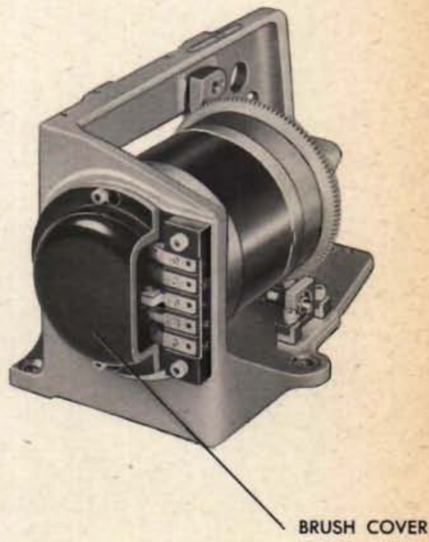


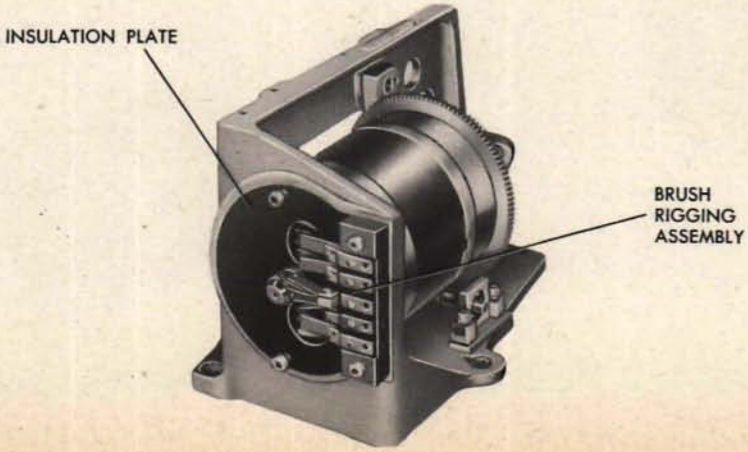
8 Remove the heart-cam assembly and spacer.

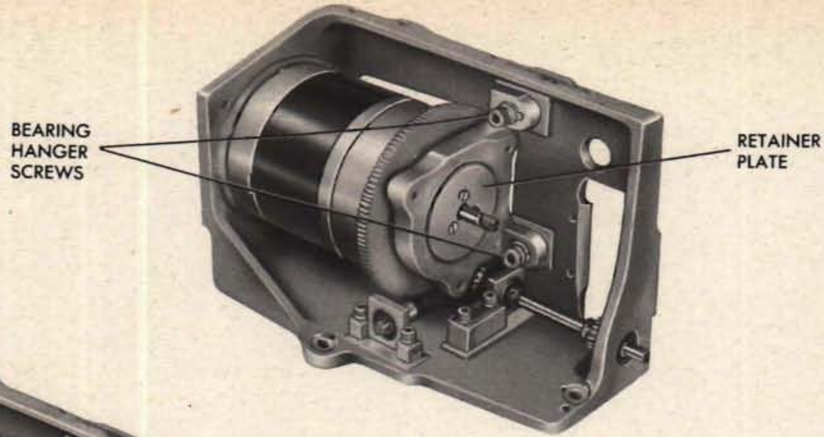
9 From the other end, remove the brush cover.

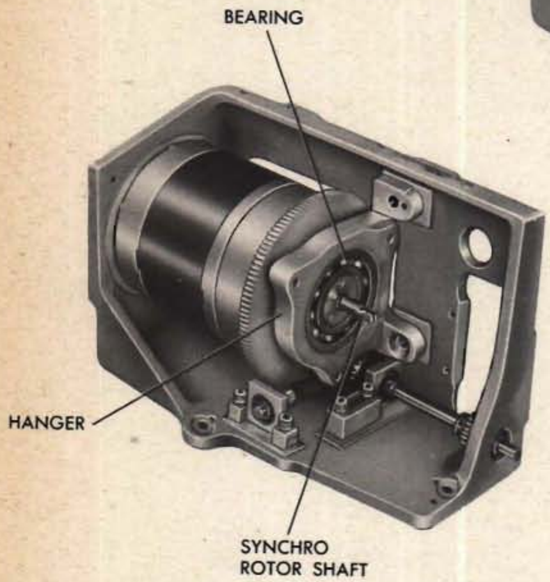
10 Remove the brush rigging assembly.

11 Remove the insulation plate.









12 Remove the retainer plate.

13 Unscrew the two screws which secure the large bearing hanger to the frame.

14 Gently lift the bearing hanger off its dowels. (If the dowel holes extend through the hanger feet, drive out the dowels before removing the hanger.) Remove the bearing from the hanger.

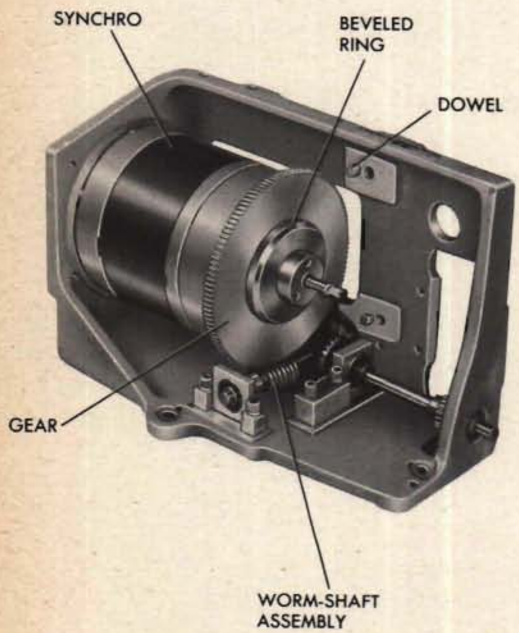
15 Remove the beveled ring.

16 Lift out the synchro motor. For instructions on disassembly of the synchro motor, refer to page 446.

17 Remove the gear only if necessary.

18 Remove the worm-shaft assembly only if necessary.

19 Remove the large bearing if it requires cleaning or replacement.

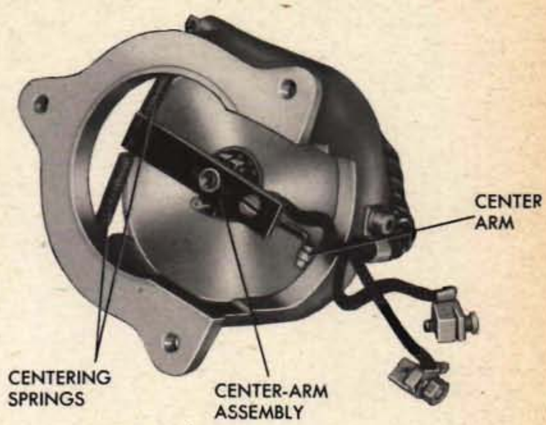


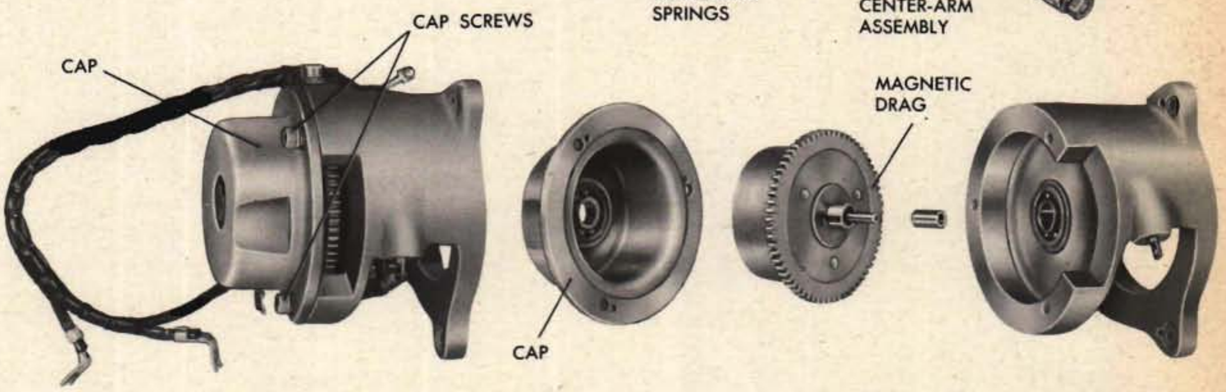
Removing the magnetic drag

20 Unhook the centering springs and loosen the clamp. Remove the center-arm assembly of the follow-up control. Tag the spacer.

21 Remove the three screws and lift off the cap.

22 Lift out the magnetic drag. Tag the spacers.





Repairing the single-speed unit

The synchro receiver is really an assembly of several basic units which are discussed in other chapters of this book. Therefore, refer to the following chapters on these units for instructions on repairing the parts of the receiver:

The Servo Motor, page 426.
The Synchro, page 444.
The Follow-up, page 402.
Basic Repair Operations, page 36.
Shaft Lines, page 92.
Wiring, page 380.

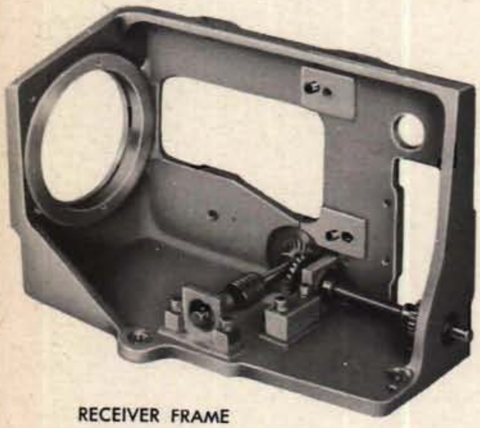
The magnetic drag

Do not disassemble the magnetic-drag subassembly unless a replacement magnetic drag or facilities for remagnetizing the drag are available.

A magnetic field generated by 40 to 60 thousand ampere-turns D.C. is required to remagnetize the drag. The magnetic drag is similar to the magnetic damper in principle and construction. For an explanation of the magnetic damper, see page 440.

Reassembling the single-speed unit

Wash the mechanical parts in an approved solvent and dry them. Apply some approved lubricant to each gear and bearing.



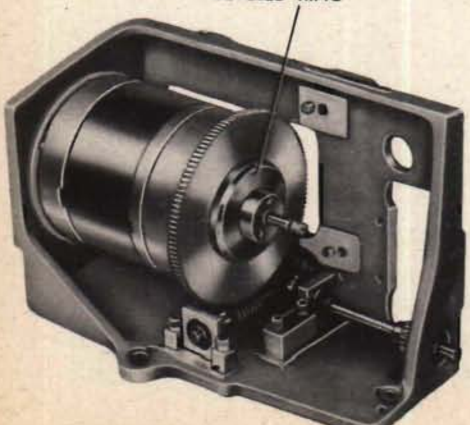
RECEIVER FRAME

SYNCHRO

BEARING

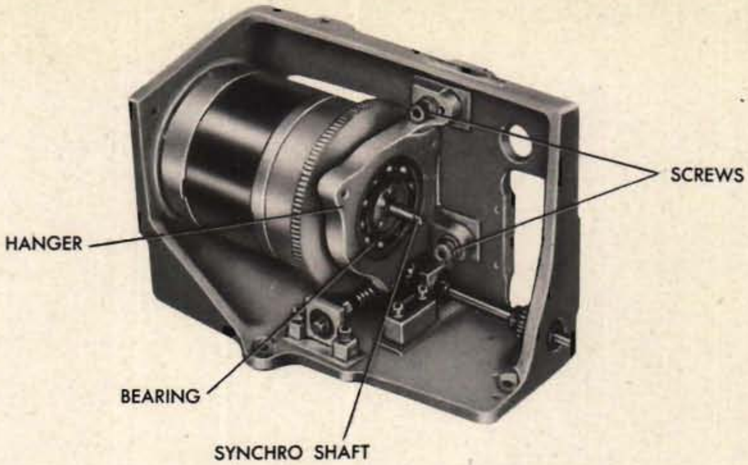
GEAR

BEVELED RING

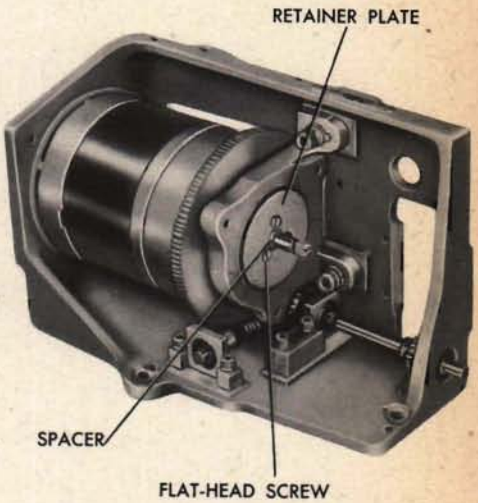


1 Mount the synchro, together with its bearing and gear, in the seat in the frame.

2 Mount the beveled ring on the gear.



3 Mount the hanger on the dowels and secure it with the two screws. Replace the bearing.



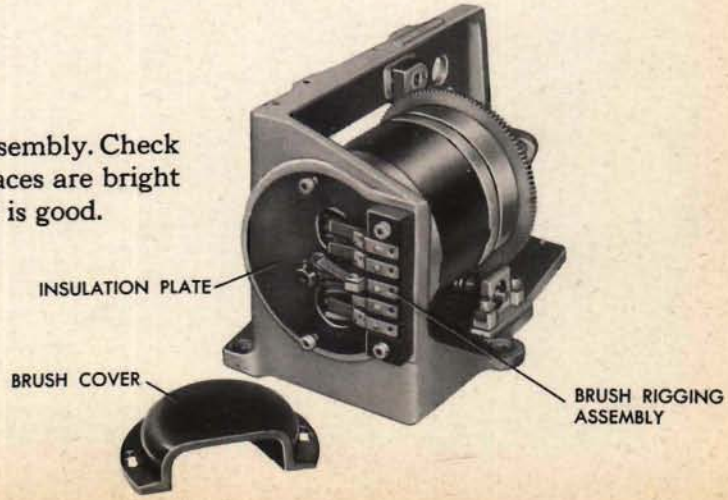
4 Mount the retainer plate and stake the three flat-head screws.

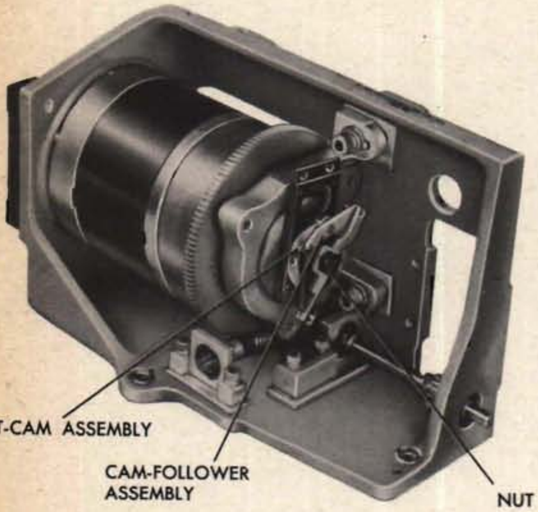
5 Put the spacer on the synchro shaft.

6 Mount the insulation plate.

7 Mount the brush rigging assembly. Check to be sure the contact surfaces are bright and clean and that contact is good.

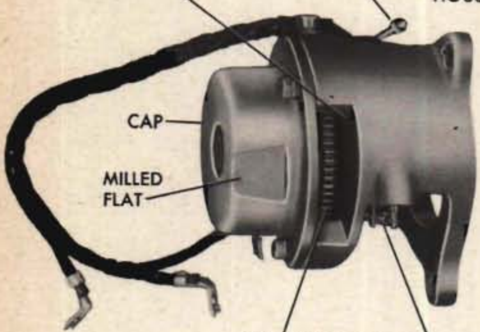
8 Mount the brush cover.





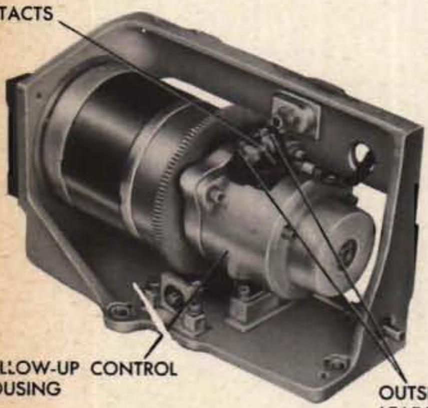
9 Mount the heart-cam assembly on the synchro rotor shaft.

10 Mount the cam-follower assembly and secure it with the nut.



11 Install the magnetic drag in the housing with its spacers. Replace the cap being sure to have the milled flat on the side of the cap opposite the cutaway in the housing.

12 Mount the center contact arm and spacer on the magnetic drag shaft and tighten the small assembly clamp. Replace the centering springs.



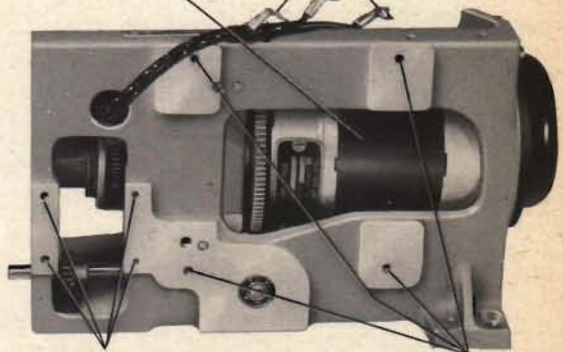
13 Mount the follow-up control housing.

14 Install the outside contacts and leads and adjust the contacts.

15 Mount the friction relief and its hangers.

16 Mount the servo motor and capacitor.

17 Connect the leads to the servo terminal block.



Bench checking the single-speed unit

1 Check the assembly of the unit against the assembly drawing.

2 Gear meshes should be free with a minimum of lost motion.

3 Contacts should be aligned to meet squarely. Be sure they are adjusted close enough to reduce the dead space to a minimum without causing arcing or jiggling.

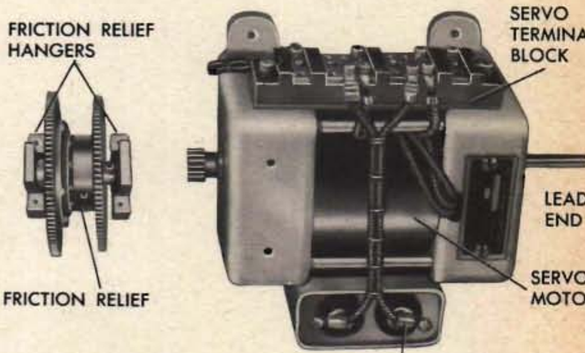
4 Check to be sure that there are no grounded wires. Check to be sure that fish paper has been placed under the wire clamps.

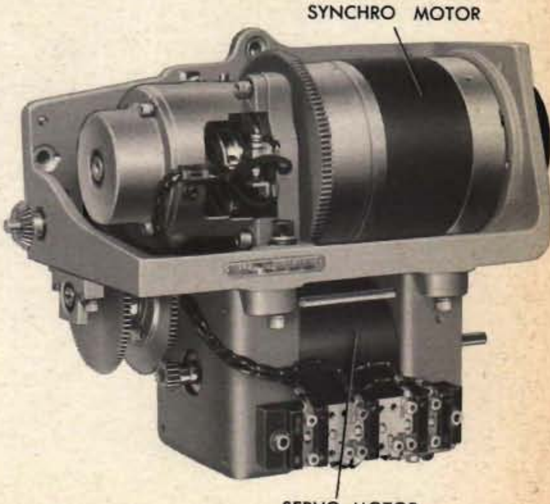
5 Apply 115-volt A.C. to single and double-letter terminals of the servo motor block. When the contacts are offset by hand, the motor should run in the direction which corresponds with the contact being made. The No. 1 contact should cause the motor to run clockwise as viewed from the lead end of the motor.

6 Connect a synchro generator to the receiver synchro and energize the follow-up. With a fixed input signal, the receiver should synchronize and hold steady in agreement with the signal.

7 When the input signal is varied the receiver should follow smoothly.

8 Check to be sure that the friction relief is set according to instructions on the assembly drawing.

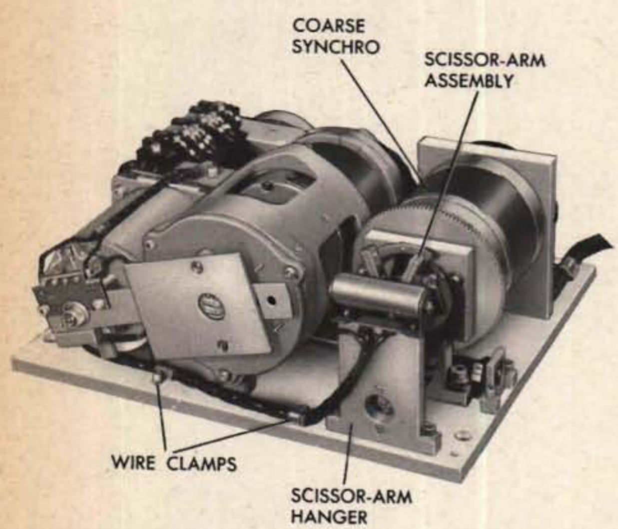




Disassembling the double-speed unit

The major assemblies of a double-speed receiver may be removed and disassembled independently. The procedure will be described in the following order:

Removing the coarse synchro assembly.
Removing the fine synchro motor and jewel differential assembly.
Removing the servo motor and compensator assembly.
Removing the contacts and wires.



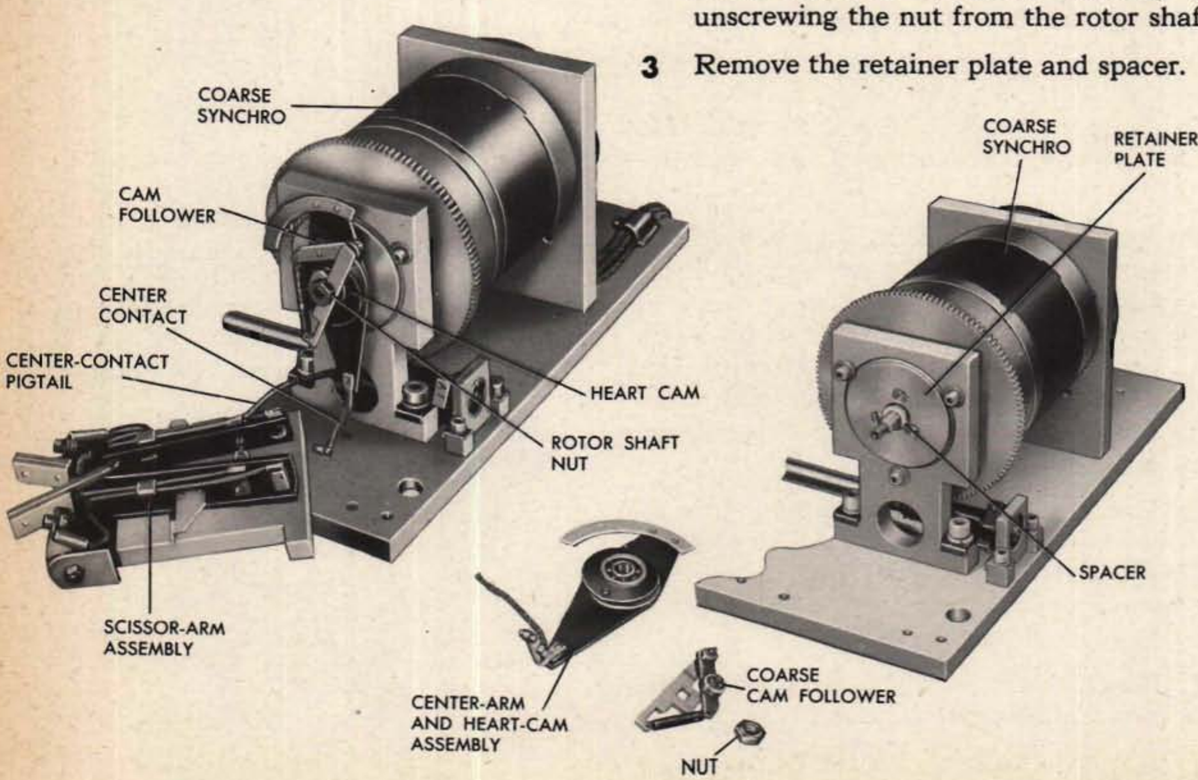
DOUBLE-SPEED RECEIVER

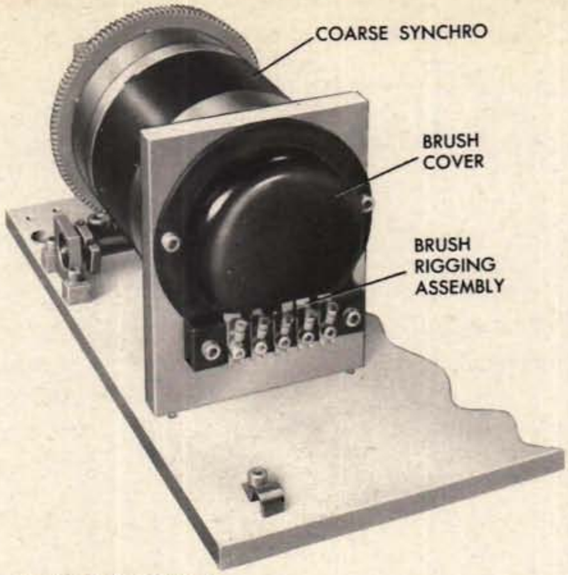
Removing the coarse synchro assembly

1 Remove the scissor-arm hanger to which the scissor-arm assembly and coarse synchro contacts are attached. The pigtail will remain attached to the coarse center contact. Remove the wire clamps.

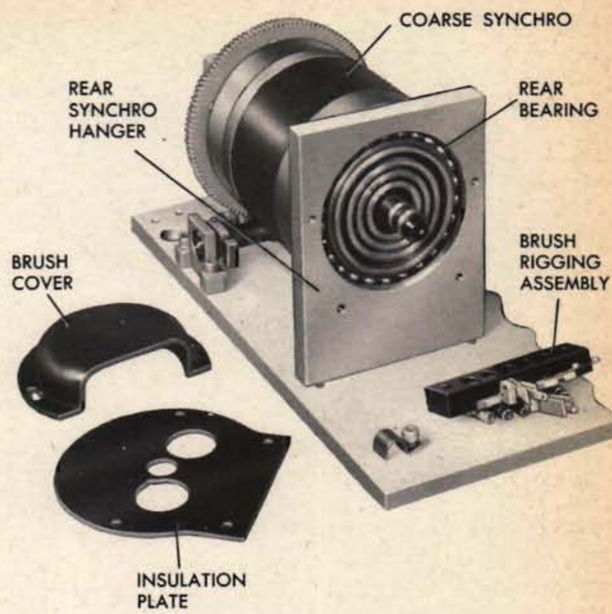
2 Remove the coarse cam follower and the center-arm and heart-cam assembly by unscrewing the nut from the rotor shaft.

3 Remove the retainer plate and spacer.





COARSE SYNCHRO
REAR VIEW

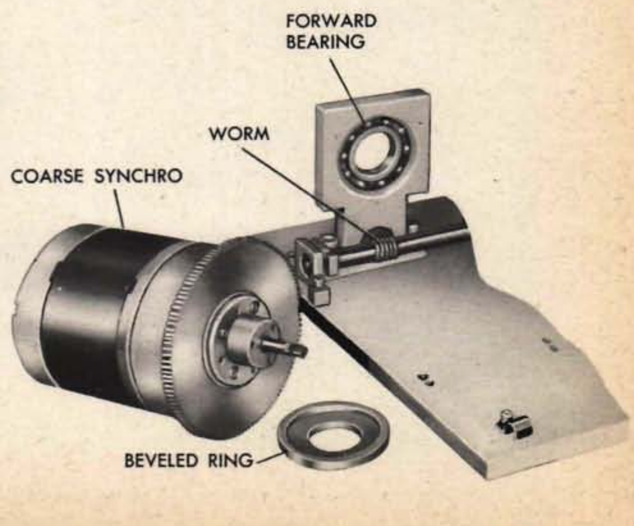


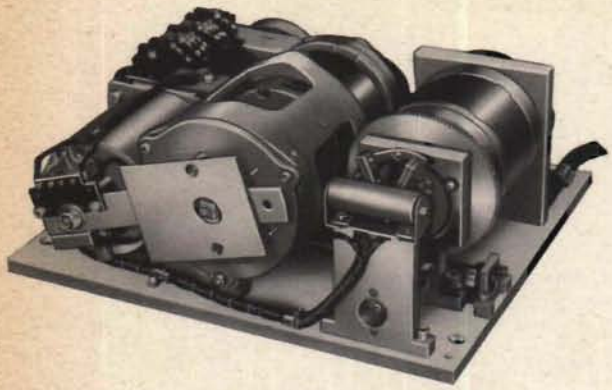
4 Remove the brush cover, the brush rigging assembly, and the insulation plate.

5 From the bottom of the plate, loosen the screws of the rear synchro hanger and pull off the hanger and bearing.

6 Pull the coarse synchro out of its forward bearing and remove the beveled ring from the big gear.

7 If necessary, remove the worm which is mounted between hangers on the base plate.

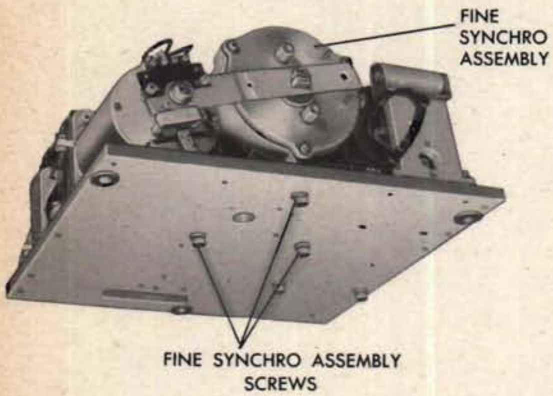




DOUBLE-SPEED RECEIVER

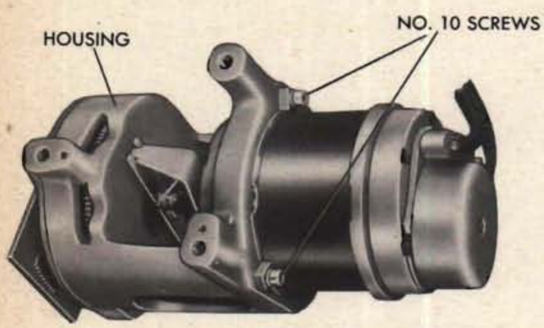
Removing the fine synchro motor and jewel differential assembly

1 Loosen the three ¼-20 screws on the bottom of the plate and gently lift up the housing to remove the fine synchro assembly. The legs are doweled. Be careful not to injure the delicate jewel differential shaft.



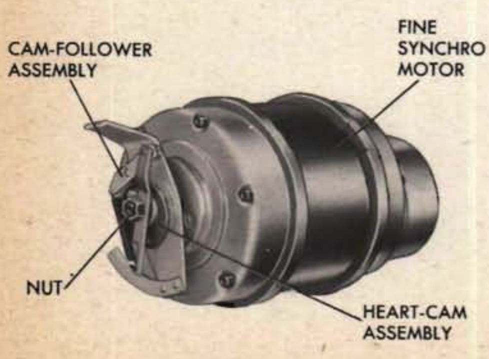
2 Loosen the three No. 10 screws and lift out the synchro.

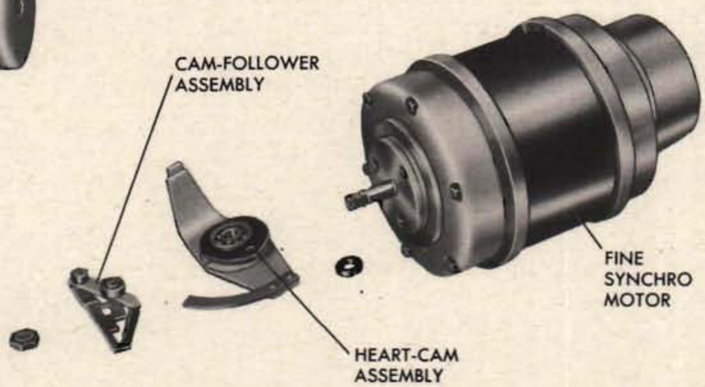
3 Loosen the nut on the rotor shaft and remove the cam-follower and heart-cam assemblies.

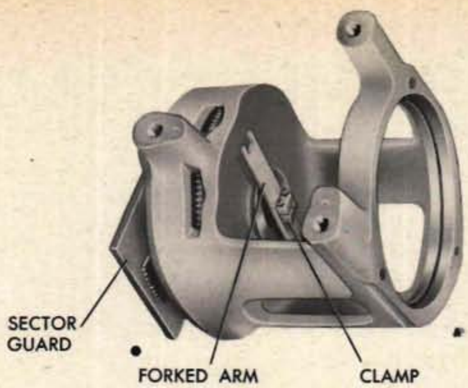


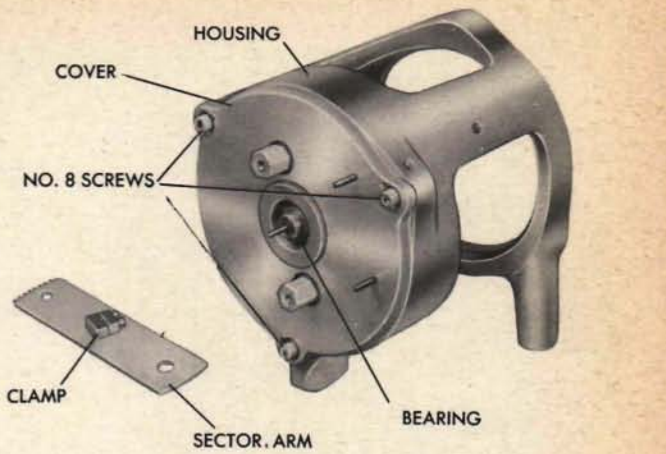
FINE SYNCHRO ASSEMBLY

4 If the synchro motor needs repairing, refer to page 444.

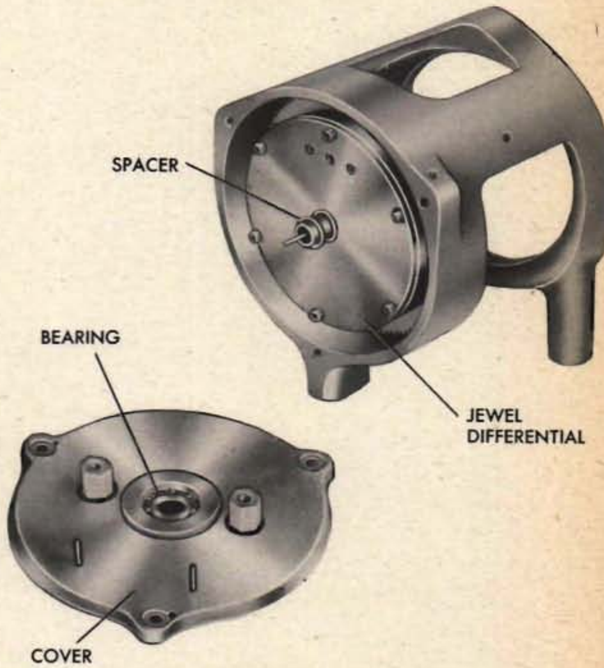






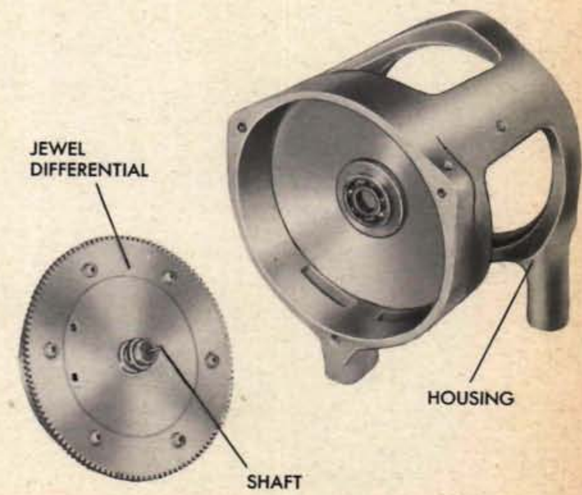


5 Remove the forked arm from the jewel differential by loosening the clamp.



6 Remove the sector guard. Loosen the clamp and remove the sector arm from the jewel differential.

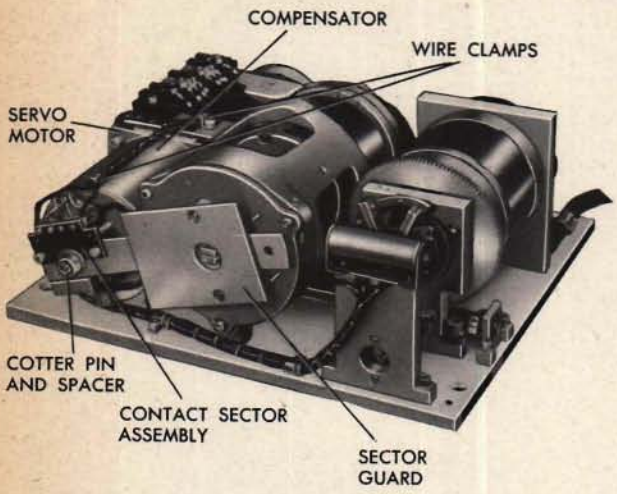
7 Loosen the three No. 8 screws and remove the cover from the housing. Tag the spacer and the bearings.



8 Remove the jewel differential by pulling it carefully out of its rear bearing in the housing. Handle the jewel differential with extreme care. *Provide a support for the jewel differential so that its shafts will not touch the bench. Shock or other mistreatment may break a shaft or crack a jewel bearing.*

9 For instructions on disassembling the jewel differential, refer to page 182.

Removing the servo motor and compensator assembly



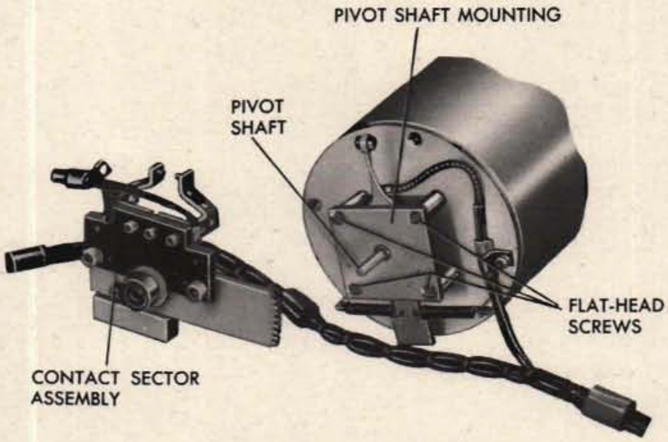
DOUBLE-SPEED RECEIVER

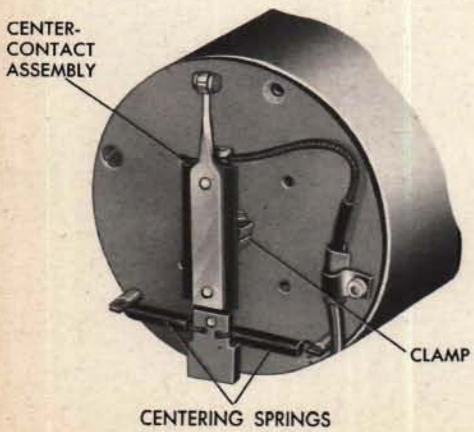
1 Remove the wire clamps and sector guard.

2 Pull out the cotter pin. Remove and tag the spacer.

3 Pull the contact sector assembly off the pivot shaft.

4 Unscrew the four flat-head screws and remove the pivot shaft mounting.





5 Unhook the centering springs, loosen the clamp, and lift off the center contact assembly.

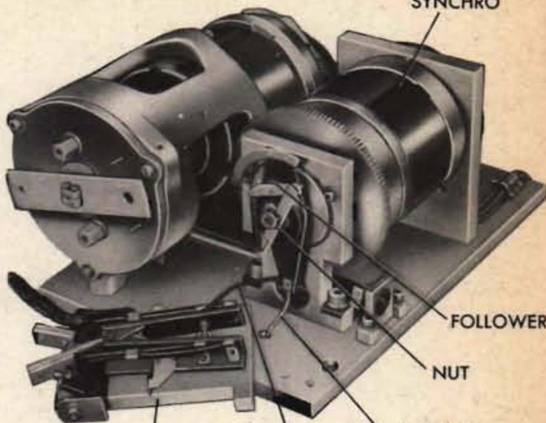
6 Disconnect the leads from the servo motor block.

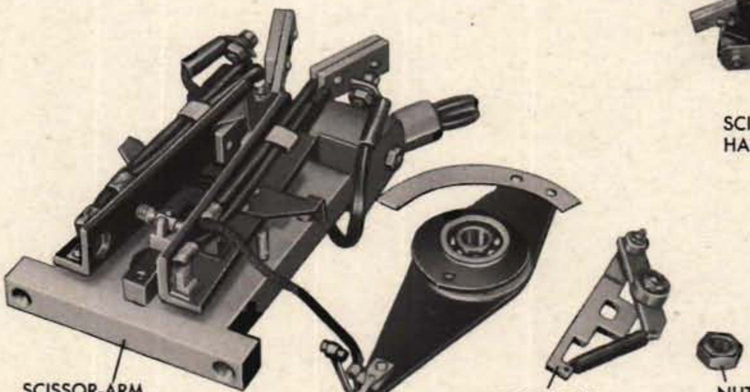
7 Unscrew the No. 10 screws in the motor feet and remove the motor and compensator assembly. For instructions on disassembling the servo motor, refer to page 426. For instructions on disassembling the compensator and removing the magnetic drag, refer to page 413.

Removing the contacts and wires

1 Remove the coarse scissor-arm hanger. **CAUTION:** Do not pull the hanger away. It is connected to the center pigtail.

2 Loosen the nut on the coarse synchro rotor and remove the coarse cam follower and center-contact assemblies.





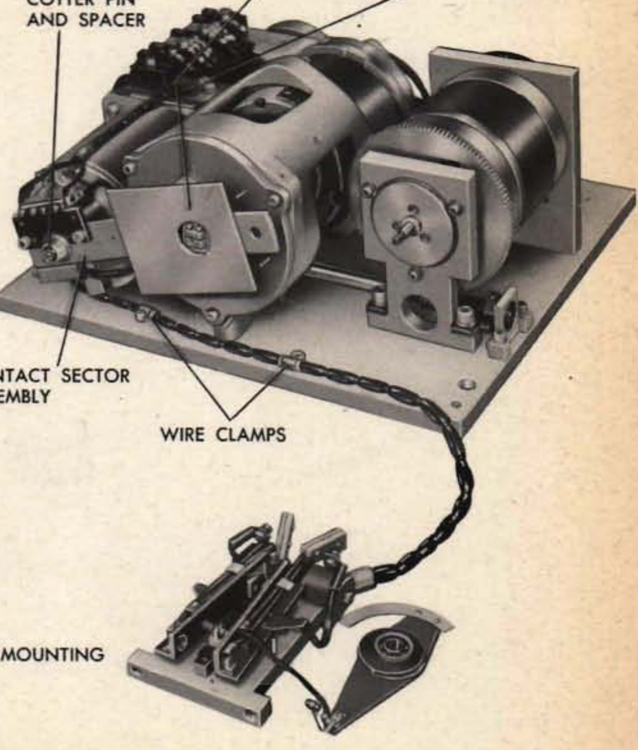
3 Remove the wire clamps.

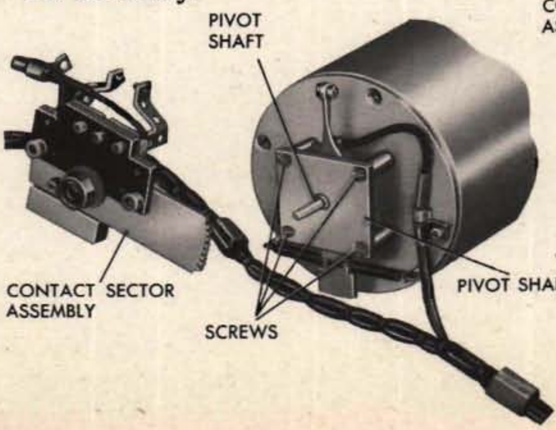
4 Remove the sector guard.

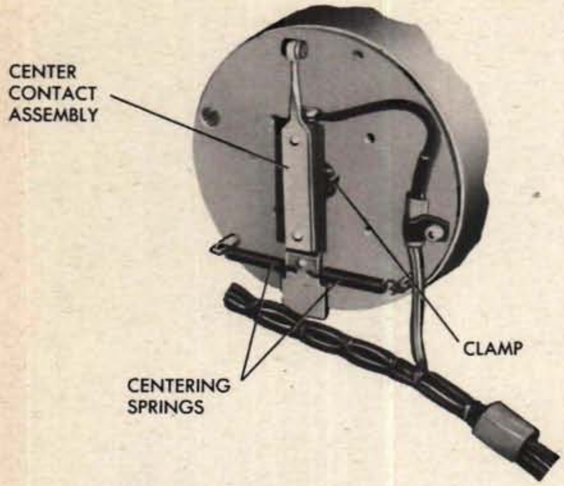
5 Pull out the cotter pin. Remove and tag the spacer.

6 Take the contact sector assembly off the pivot shaft.

7 Unscrew the four flat-head screws securing the pivot shaft mounting and remove the assembly.



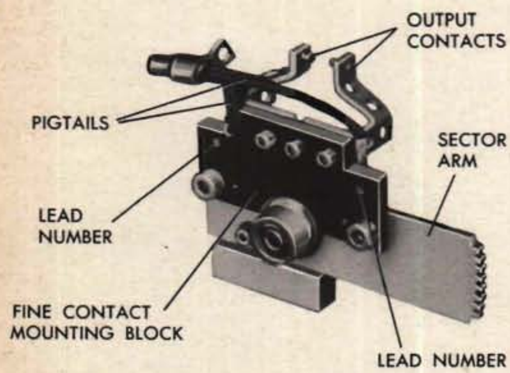




8 Loosen the clamp on the center-contact assembly.

9 Unhook the centering springs and remove the center-contact assembly.

10 Disconnect the leads frum the servo motor block.

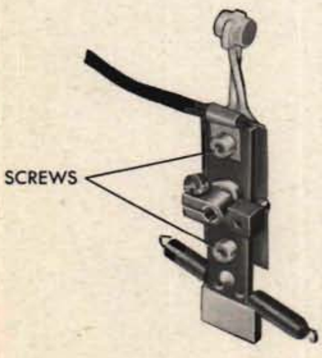


SECTOR ASSEMBLY

11 Remove the fine outside contacts from the contact sector assembly.

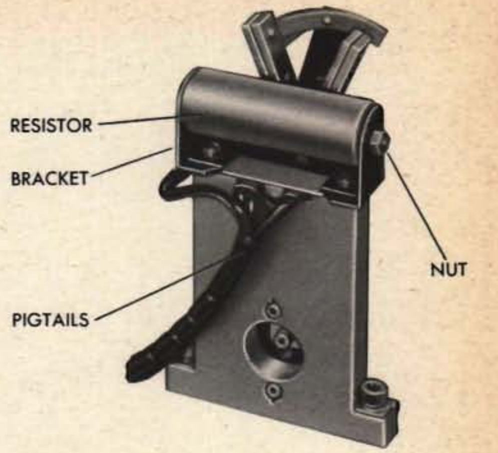
12 Tag the pigtails with numbers corresponding to those stamped on the mounting block.

13 Remove the fine contact mounting block and the counterweight from the sector arm.



FINE CENTER-CONTACT ASSEMBLY

14 Loosen the screws holding the fine center-contact assembly together. Take the assembly apart.

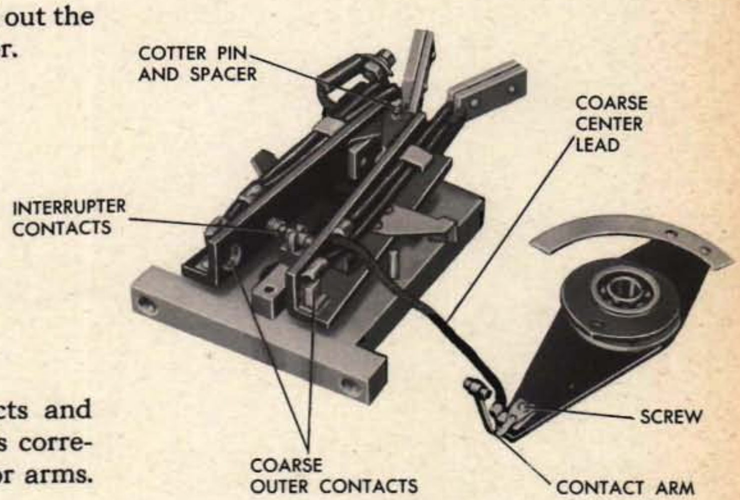


15 Unscrew one of the nuts and pull the rod out of the resistor.

16 Remove the resistor brackets to free the pigtails.

17 Remove the coarse center lead and contact arm by taking out the small flathead screw.

18 To remove the scissor arms, pull out the cotter pin and remove the spacer.



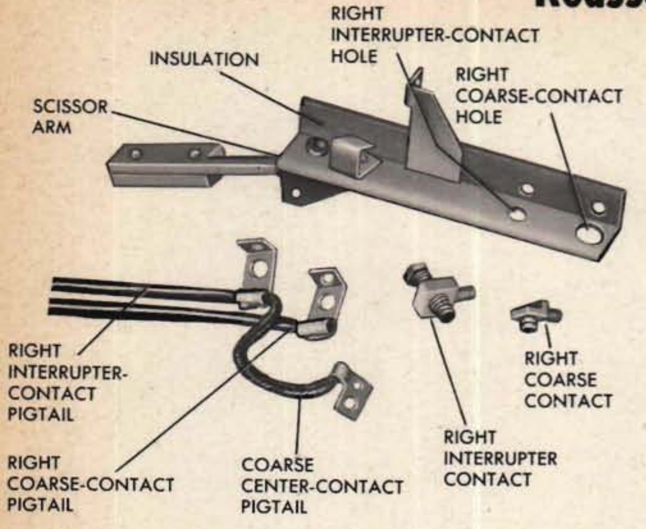
19 Remove the interrupter contacts and coarse outer contacts. Tag leads corresponding to stampings on scissor arms.

Repairing the double-speed unit

The double-speed synchro receiver is really an assembly of several basic units which are discussed in other chapters of this book. Therefore, refer to the following chapters on these units for instructions on repairing the parts of the receiver:

Basic Repair Operations, page 36.
Shaft Lines, page 92.
The Jewel Differential, page 182.
Wiring, page 380.
The Follow-up, page 402.
The Servo Motor, page 426.
The Synchro, page 444.

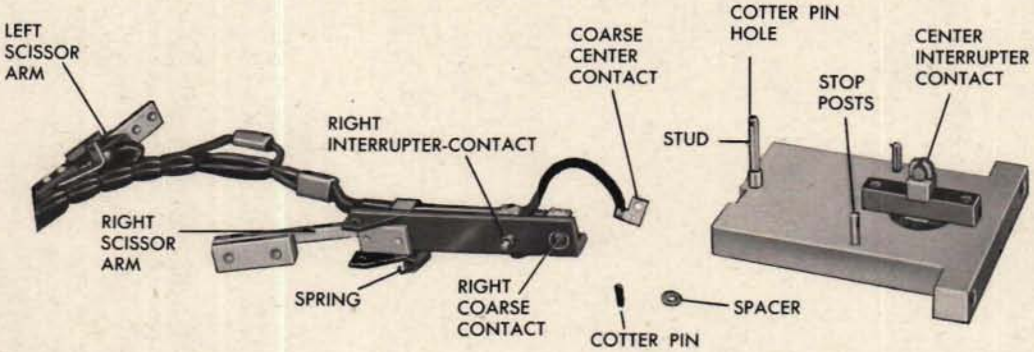
Reassembling the double-speed unit

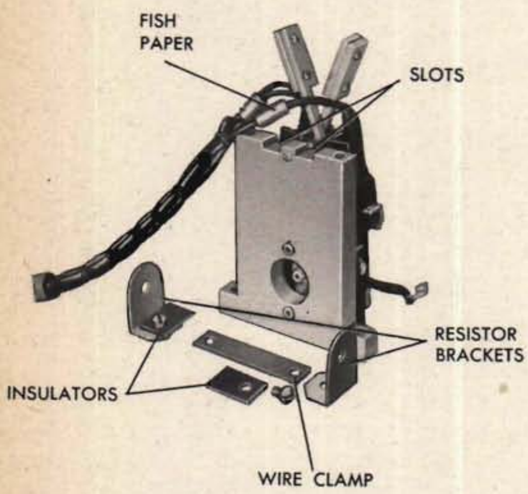


1 Attach the pigtails and contacts to the scissor arms. The tags attached to the wire terminals should correspond to the numbers stamped on the insulating material.

2 Place the scissor arms on the stud, keeping the arms between the stop posts. Secure them with the spacer and cotter pin, making sure that they pivot freely on the stud.

3 Attach the spring that holds the arms together.

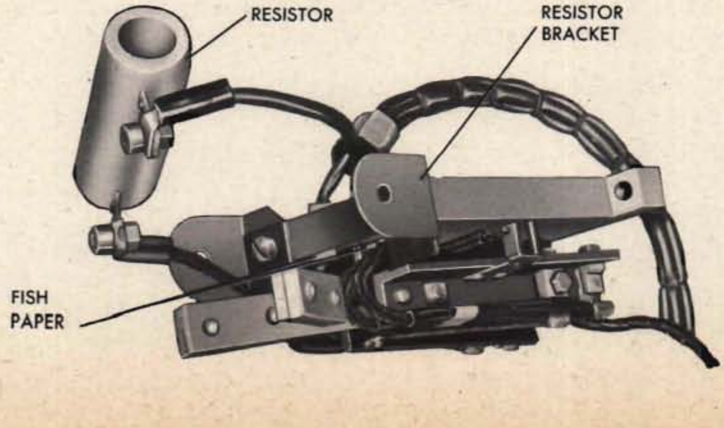


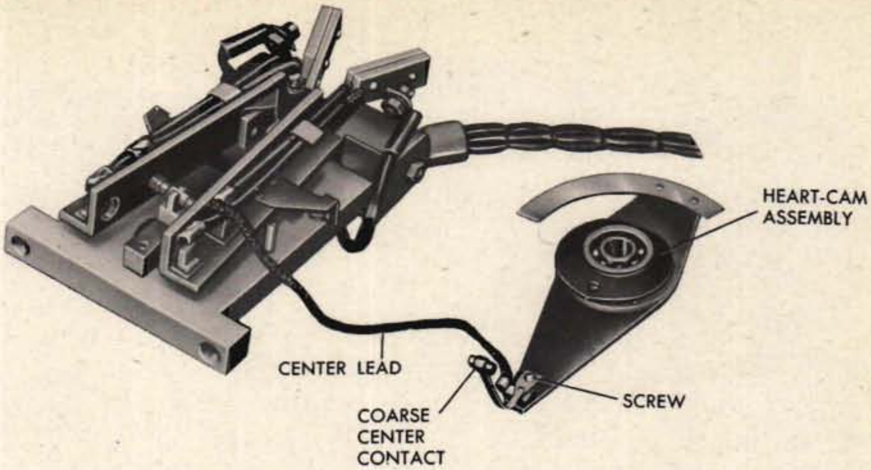


4 Cover the pigtails with fish paper and insert them in the slots.

5 Mount the wire clamp, resistor brackets, and insulators, with the insulators extending toward the scissor arms.

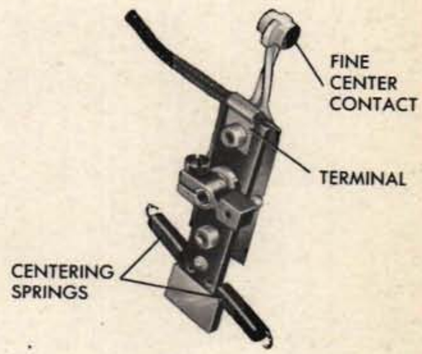
6 Put the resistor, the aluminum washers, and the mica insulators in place between the brackets. Insert the rod and tighten the nuts.





7 Screw the center lead and coarse center contact to the heart-cam assembly.

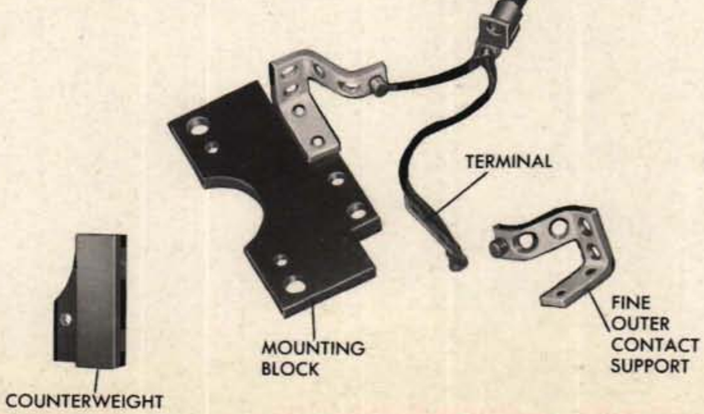
8 Reassemble the fine center contact and terminal.

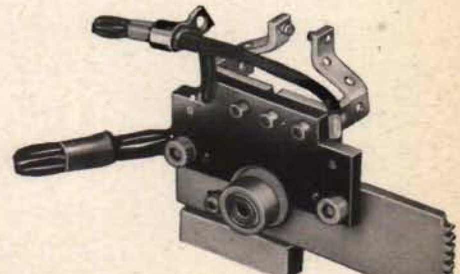


FINE CENTER-CONTACT ASSEMBLY

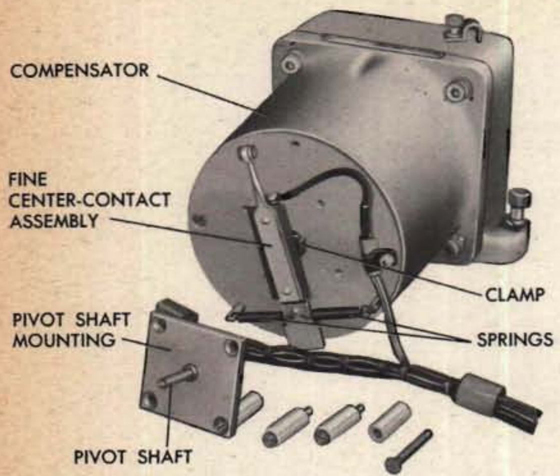
9 Assemble the fine outer contact supports and terminals. Screw them to the mounting block. Attach the terminals according to the tags attached at disassembly.

10 Assemble the fine outer contacts and the counterweight on the sector.





FINE OUTER CONTACTS
AND SCISSOR-ARM ASSEMBLY



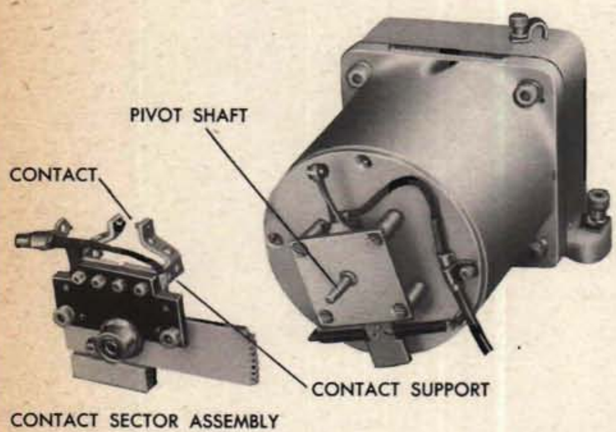
11 Mount the fine center-contact assembly on the magnetic drag shaft extension.

12 Attach the center-contact springs and tighten the clamp.

13 Replace the contact sector pivot shaft mounting on the compensator cover. Stake the four flat-head screws.

14 Slip the contact sector assembly and the spacer on the pivot shaft. Secure them with a cotter pin.

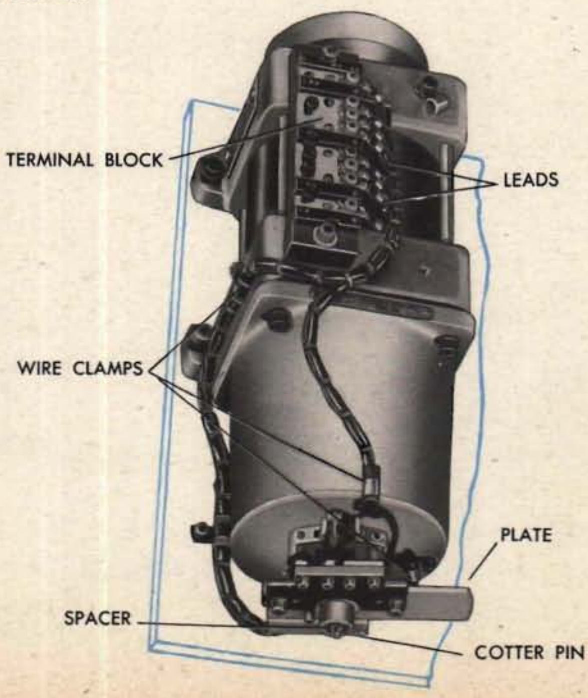
15 Adjust the outside contacts by moving their supports within the clearance of the mounting holes. The contact surfaces should be made parallel with a total gap of about 0.015 inch.



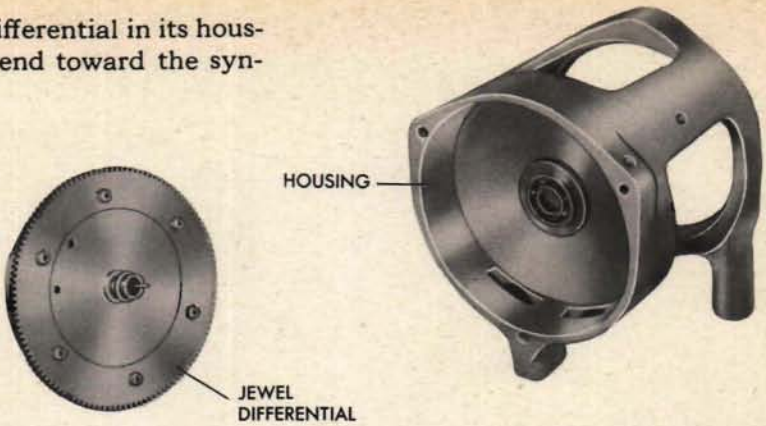
16 Mount the servo motor and compensator assembly on the plate.

17 Connect the leads to the servo terminal block.

18 Replace the wire clamps.

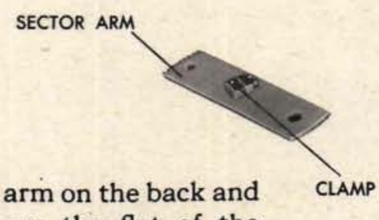


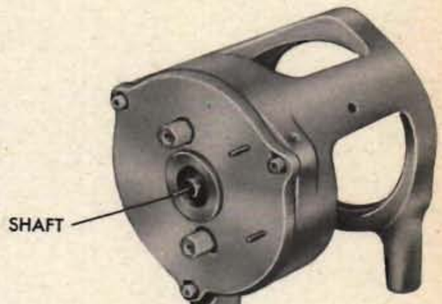
19 Mount the jewel differential in its housing with the gear end toward the synchro.



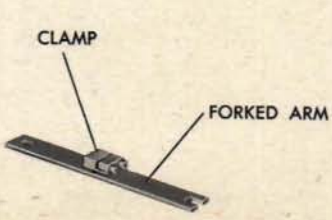
20 Replace the cover and bearing.

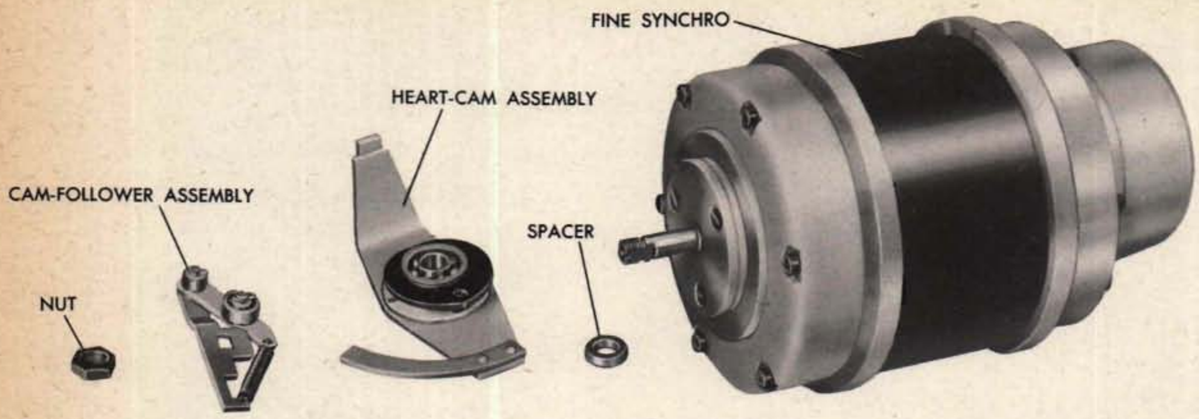
21 Replace the sector arm. *Be sure that the clamp is tightened on the flat of the shaft.*

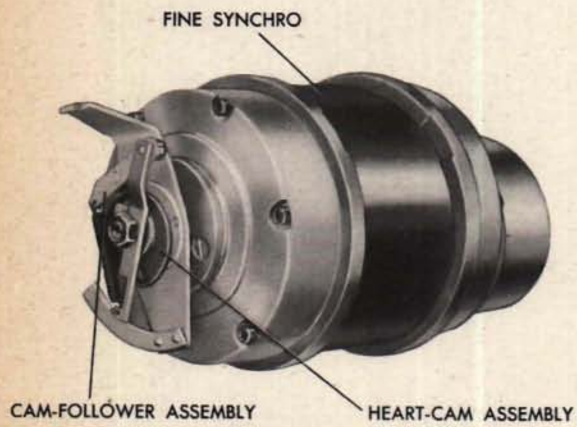




22 Replace the forked arm on the back and tighten the clamp on the flat of the shaft.



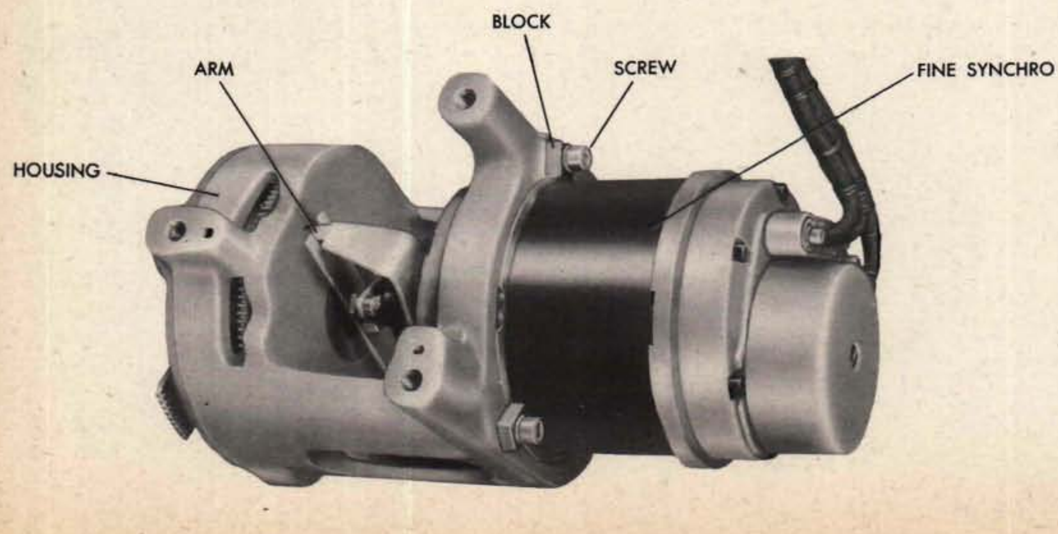


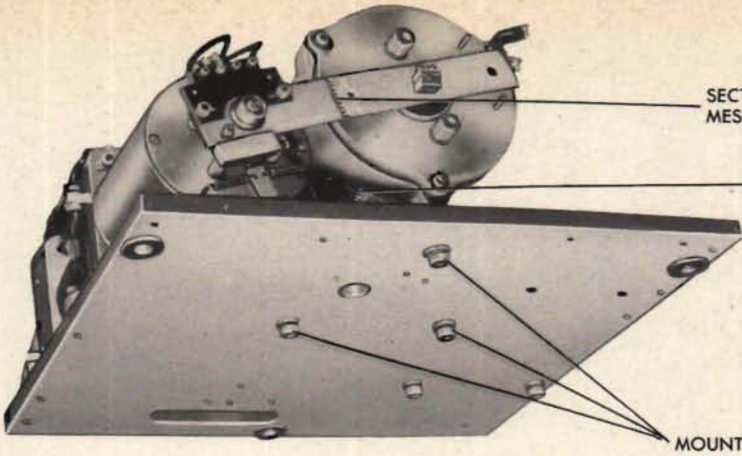


23 Mount the spacer and heart-cam assembly on the synchro rotor shaft.

24 Mount the cam-follower assembly and secure it with the nut.

25 Mount the fine synchro in the housing, carefully engaging the arm on the heart-cam assembly in the forked arm on the jewel differential. Secure the synchro with the blocks and screws.

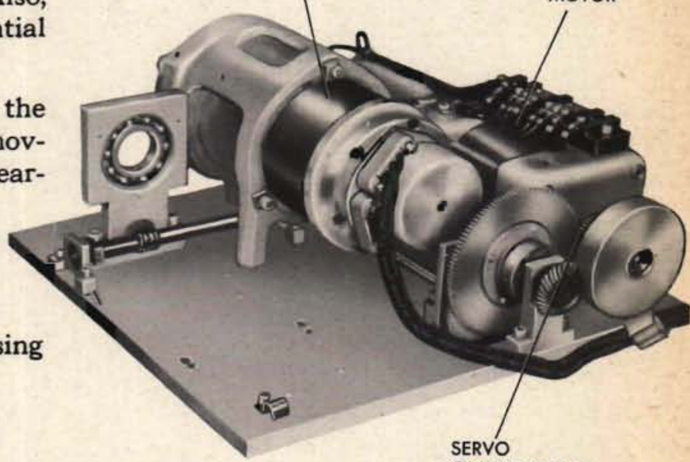




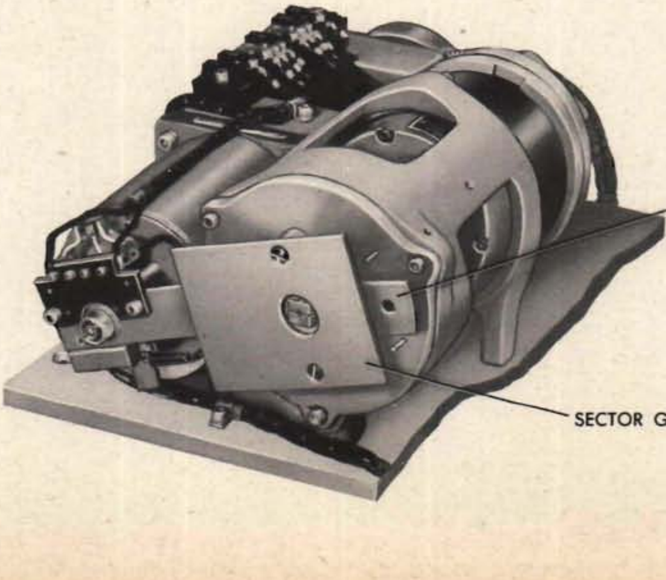
26 Remount the fine synchro assembly on the plate.

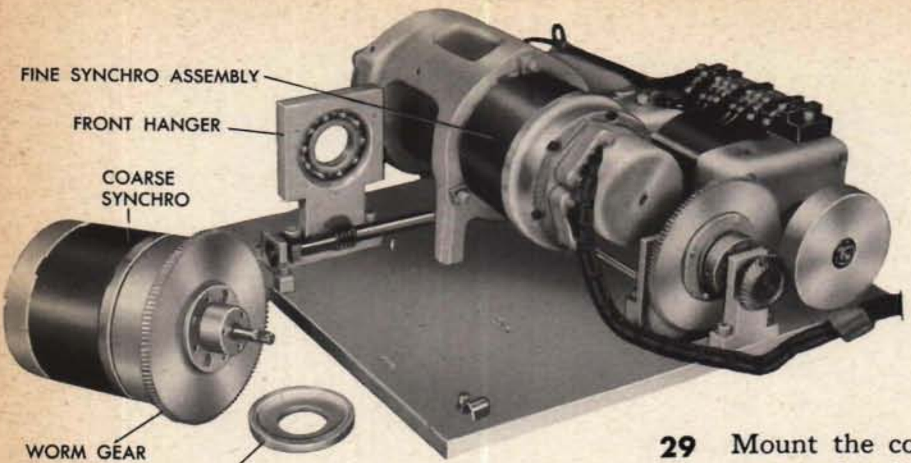
CAUTION: To avoid damage to the spider ring gear on the jewel differential, be sure that it is properly meshed before screwing the housing to the plate. Also, avoid straining the jewel differential shaft when meshing the sectors.

27 Adjust the sector gear mesh and the servo motor output gear mesh, by moving the servo motor within the clearance of the mounting holes.



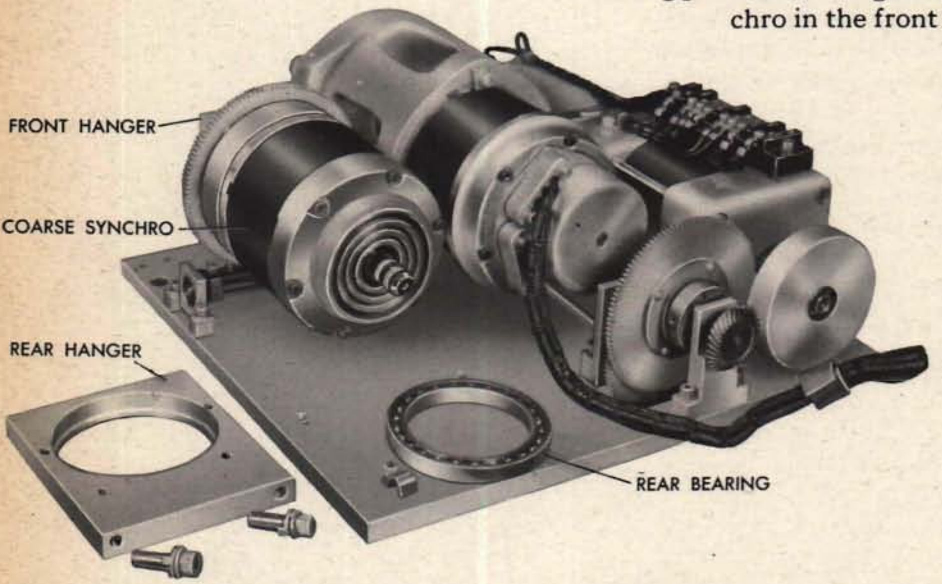
28 Mount the sector guard on the housing cover.





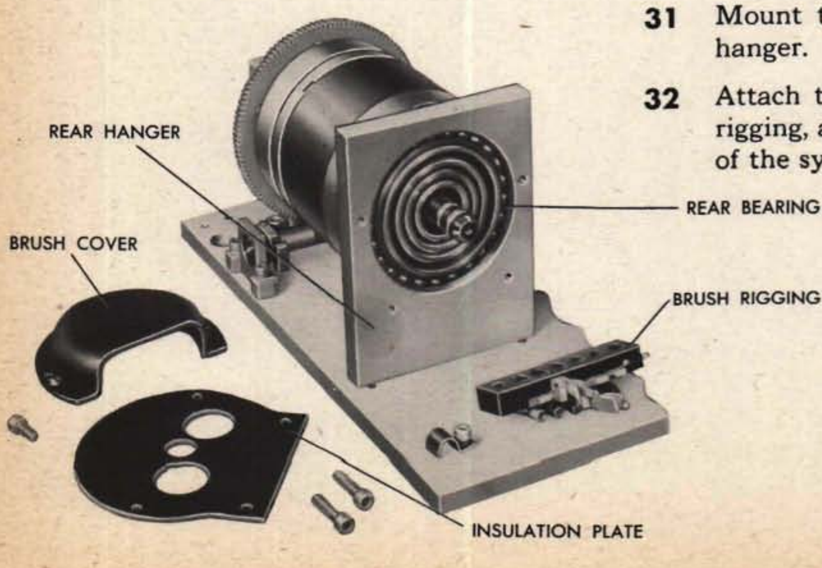
29 Mount the coarse-synchro worm gear and the beveled ring on the coarse synchro.

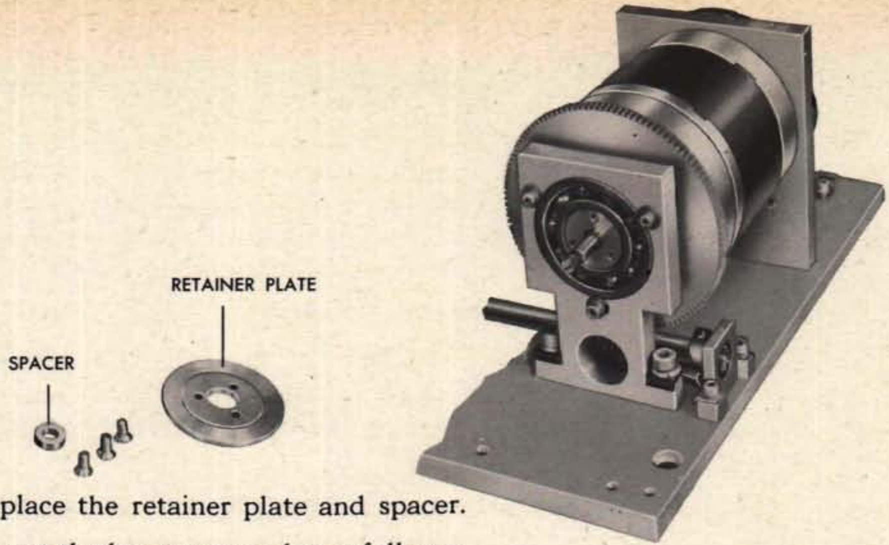
30 Insert the gear end of the coarse synchro in the front hanger.



31 Mount the rear bearing and the rear hanger.

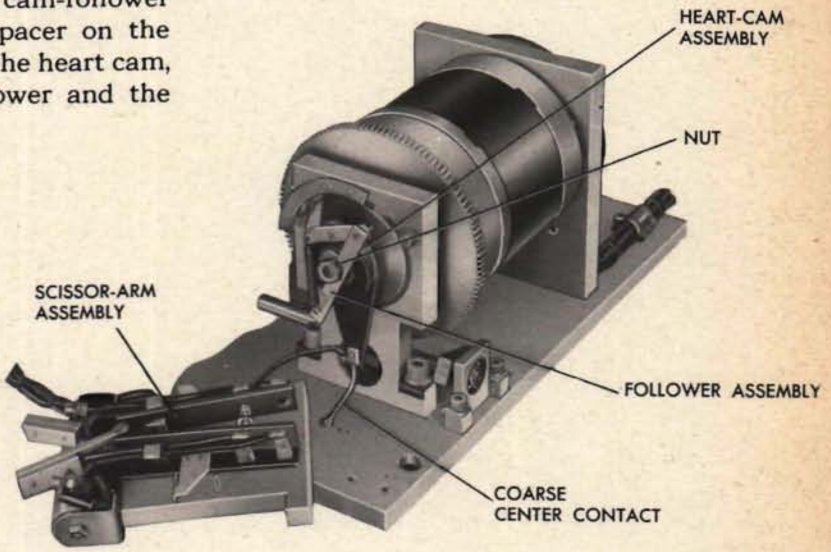
32 Attach the insulation plate, the brush rigging, and the brush cover to the rear of the synchro.





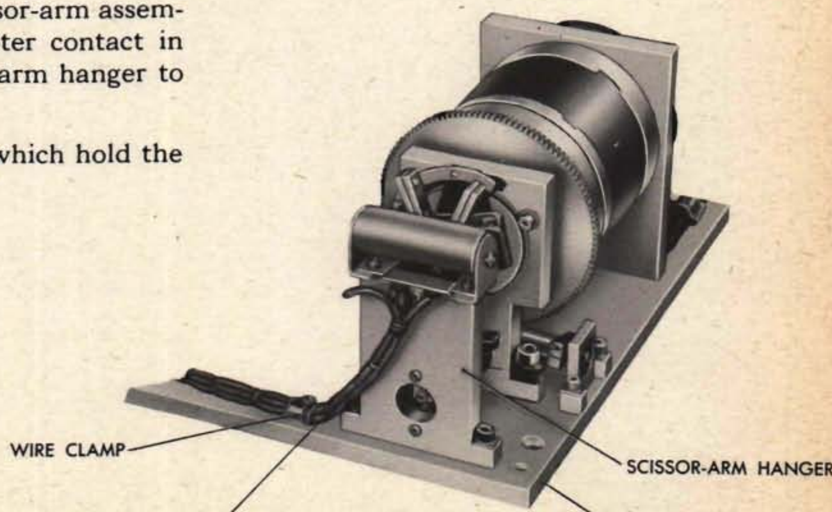
33 Replace the retainer plate and spacer.

34 Mount the heart-cam and cam-follower assemblies. First put a spacer on the synchro rotor shaft, then the heart cam, and finally the cam follower and the nut.



35 Carefully mount the scissor-arm assembly with the coarse center contact in place. Screw the scissor-arm hanger to the plate.

36 Secure the wire clamps which hold the leads to the plate.



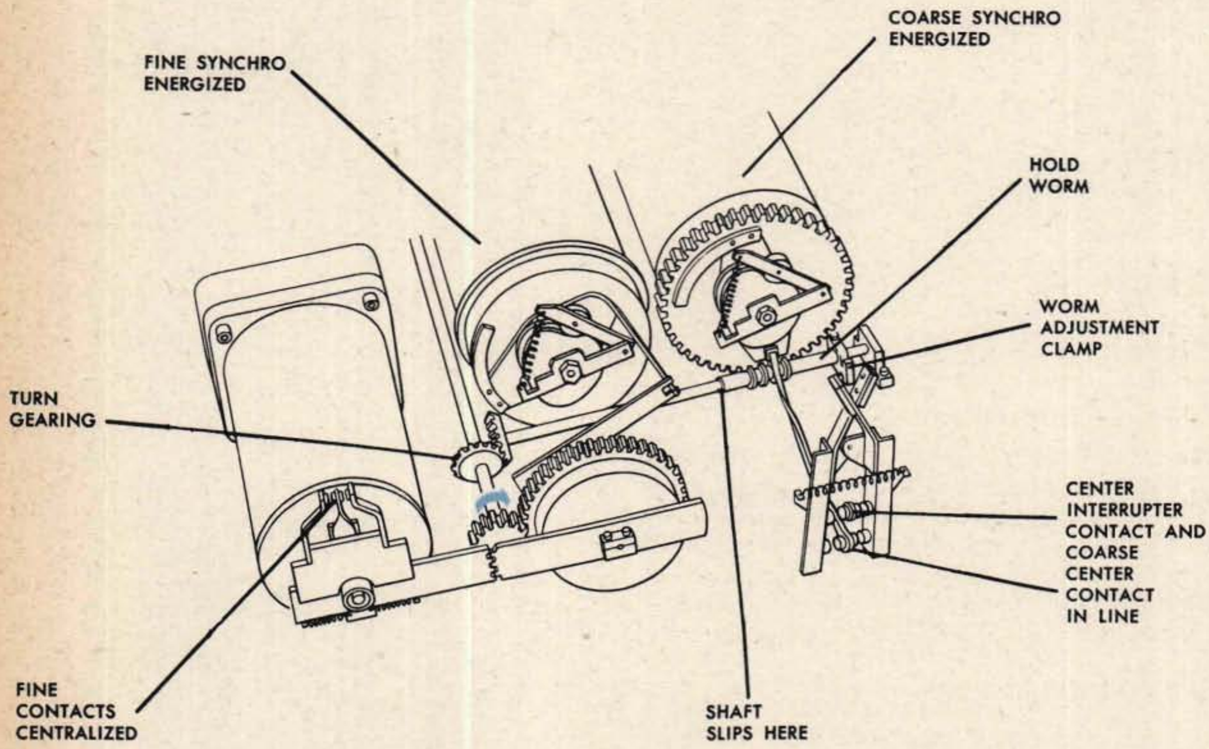
Adjusting the electrical relationship

1 Wire a transmitter to the receiver. In order to insure correct rotation, carefully observe standard Navy wiring practice. The fine and coarse generators of the transmitter must be geared together in the same ratio as the receiver motors and have proper electrical relationship to each other.

2 With the servo power OFF, energize the two synchros. Adjust the worm clamp so that it is slip-tight.

Turn the gearing by hand until the coarse center contact is exactly in line with the center interrupter contact.

3 Keep the coarse synchro stator in this position by holding the worm and turn the gearing further until the fine center contact is midway between the two outside contacts. Tighten the worm adjustment clamp.



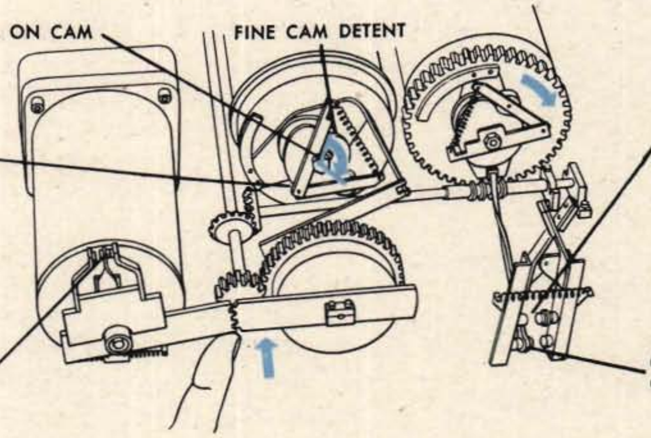
Adjusting the interrupter contacts

1 Screw in each of the outside contacts an equal number of turns.

2 Energize the servo motor.

3 Offset the fine contacts so that the motor drives the coarse stator to the point where the coarse center contact makes and the interrupter contacts open. For each direction of rotation, observe how far the fine cam follower travels out of the heart-cam detent, before the interrupter contacts open.

4 Adjust the interrupter contacts to open when the fine cam follower is one-half to two-thirds of the distance from the heart-cam detent to the peak.



Bench checking the double-speed unit

1 All gear meshes should be free and have a minimum of lost motion.

2 All taper pins should be staked and all set screws removed.

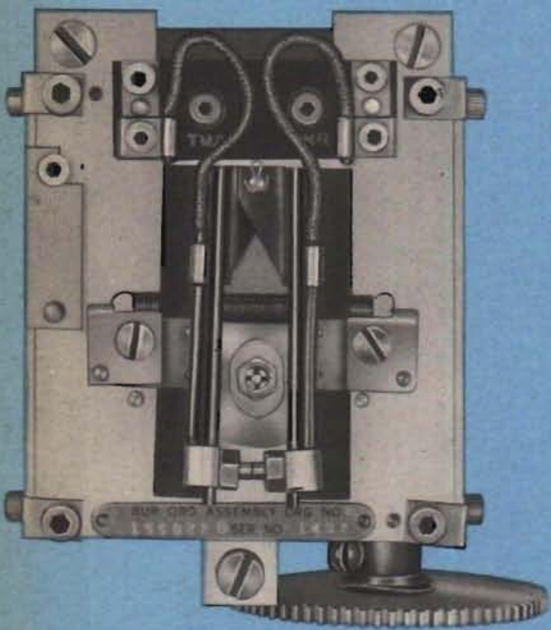
3 The fine contacts should be aligned to meet squarely and should have a total gap of about 0.015 inch. (In certain applications of the double-speed receiver, the required contact gap may be between 0.005 inch and 0.010 inch.)

4 Check to be sure that there are no grounded wires.

5 Wire a pair of standard generators according to standard Navy wiring practice and energize the servo and both synchro motors. The receiver should synchronize at one point and stand still. The receiver should smoothly follow changing signals from the transmitter. When the transmitter is turned in the increasing direction, the receiver output should also increase.

6 The friction relief should slip at the torque value indicated on the assembly drawing.

THE TIME MOTOR REGULATOR

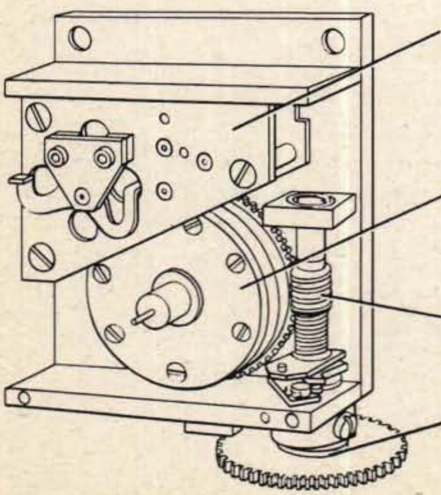


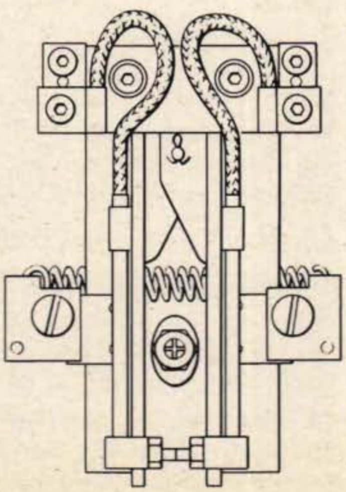
TIME MOTOR REGULATOR

The time motor regulator keeps the time motor running at a constant average speed and independent of variations in the load.

Maintenance and repair are the same for all time motor regulators using clockwork, even though they may vary slightly in design.

The time motor regulator contains five subassemblies: an escapement mechanism, a jewel differential, a friction relief, a worm shaft assembly, and a contact arm assembly.





CONTACT ARM ASSEMBLY

Typical symptoms

A time motor regulator test may indicate faulty operation due to stalling or erratic timing. These symptoms may be traced to various causes in one or more of the subassemblies.

Locating the cause

Some of the causes can be located only while the regulator is in the instrument with the time motor in operation. These are given special mention in the discussion of each subassembly.

Escapement mechanism

Stalling

The time motor regulator may stall because of jamming or sticking in the escapement mechanism.

Jamming may be caused by dirty or damaged jewel bearings or gears, a bent staff, or insufficient end play in the staff.

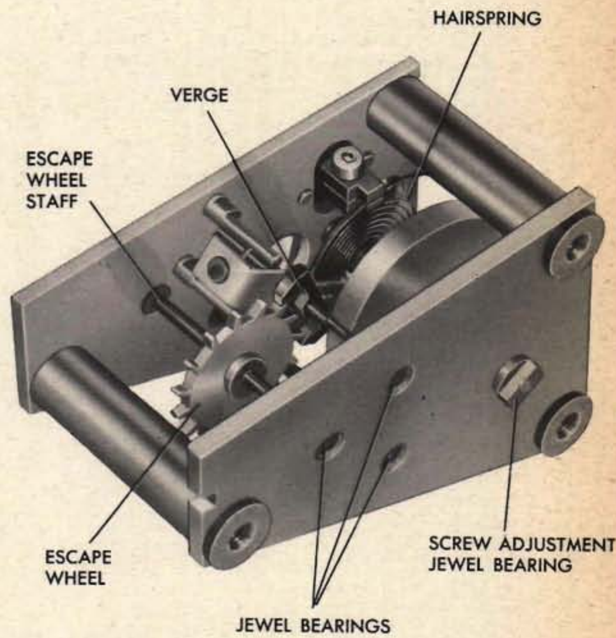
A time motor regulator which stalls periodically may be said to be sticking if it can be restarted by hand cranking. With the escapement inoperative, hand cranking causes the cam to rotate. When the high points of the cam pass the contact-arm rollers, the torque acting on the escapement reverses, thereby releasing the sticking parts.

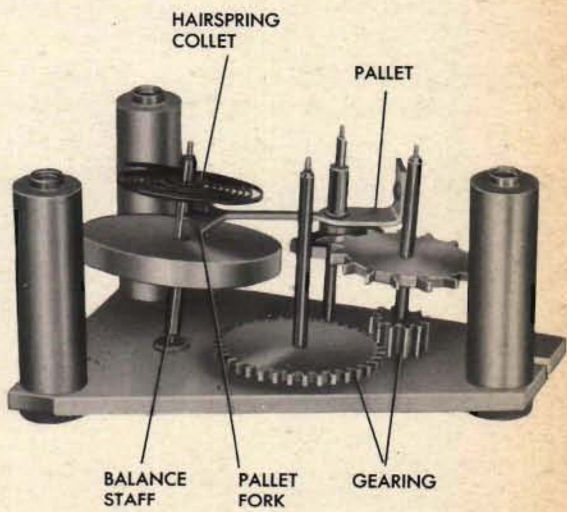
Sticking may be due to dirt or burrs on one of the escapement parts. Faulty reassembly may result in incorrect angular relationship between the pallet and verge, or incorrect clearance between the pallet fork and balance staff or between the verge and the escape wheel. These defects may also be the cause of sticking.

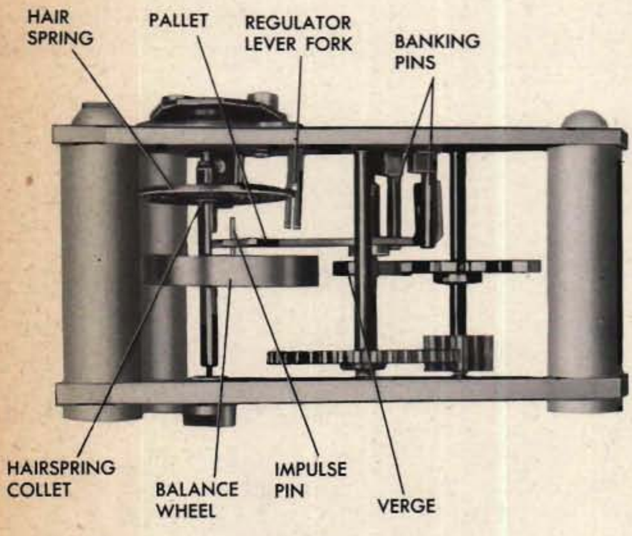
Erratic timing

Erratic timing of the time motor regulator may be due to any of the causes of stalling.

Erratic timing may also be caused by bent stop pins which will prevent correct movement of the pallet fork, or a loose collet which will upset the alignment of the impulse pin with the balance and pallet staffs.







Erratic timing (continued)

Erratic timing of the time motor regulator may be due to any of the causes of stalling. It may also be due to any of the following causes:

Bent or improperly adjusted banking pins which will prevent correct movement of the pallet and verge.

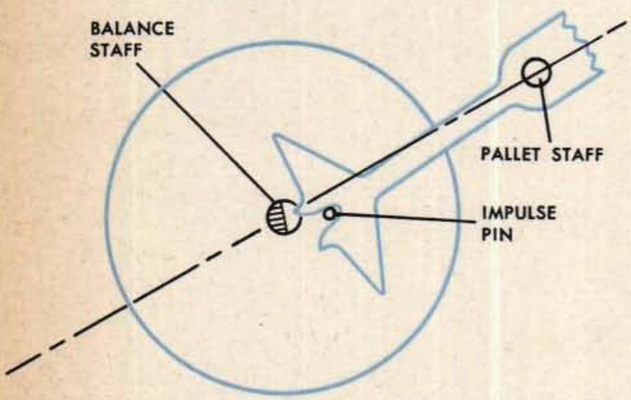
A loose or improperly adjusted hairspring collet which causes unequal swing of the impulse pin to either side of the pallet fork.

An out-of-shape hairspring, the coils of which strike each other or parts of the escapement other than the fork on the regulator lever.

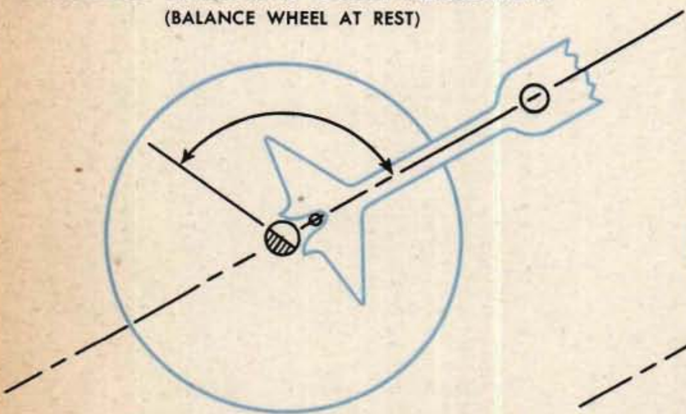
A tight or bent regulator lever fork which causes inconsistent effects when an attempt is made to adjust the timing.

A bent staff which throws the balance wheel or pallet off poise.

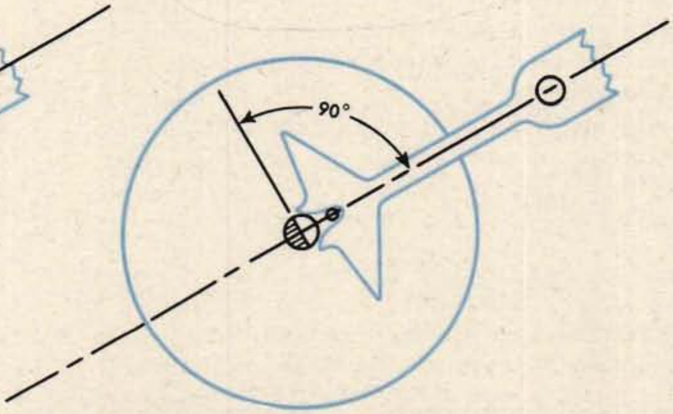
Improper alignment between the impulse pin and the recess in the balance staff.



INCORRECT HAIRSPRING COLLET ADJUSTMENT
(BALANCE WHEEL AT REST)



INCORRECT IMPULSE PIN ALIGNMENT

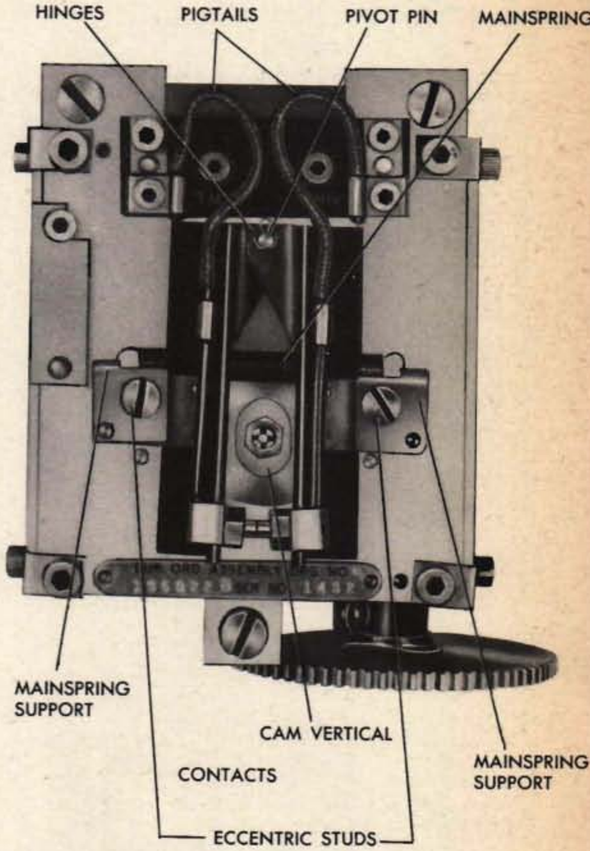


CORRECT ALIGNMENT

Contact assembly

Stalling

Stalling of the time motor regulator may be caused by electrical trouble, or by jamming or sticking in the contact assembly.



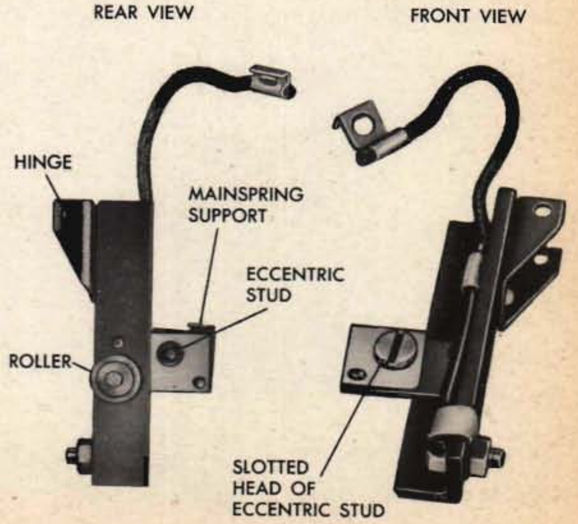
Electrical trouble can be detected only while the regulator is installed in the instrument. It may be caused by a burned-out or broken pigtail, or by dirty or damaged contacts. If the regulator starts when the contacts are together, the trouble is not electrical.

Jamming or sticking may be caused by dirty or damaged rollers. This can be detected by turning the rollers with the fingers.

Jamming or sticking may also be caused by a bent hinge or a dirty or damaged pivot pin. These causes are present if the arms do not move freely when the mainspring is removed.

Erratic timing

Erratic timing may be due to any of the causes of stalling, or it may be due to incorrect mainspring tension adjustment or improper contact adjustment.



If the eccentric studs on the mainspring supports have slipped or are improperly positioned, the wrong amount of torque will be applied to the escapement. The escapement input will also be affected if the contacts are not adjusted to open when the cam is at the angle specified on the assembly drawing.

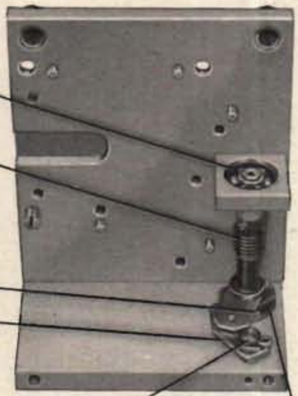
Worm shaft assembly

Stalling

Stalling of the time motor regulator may be caused by jamming, sticking, or slipping in the worm shaft assembly.

Jamming or sticking may be caused by dirty or damaged ball bearings or gears, or a bent shaft which will cause a tight mesh between the worm and the jewel differential.

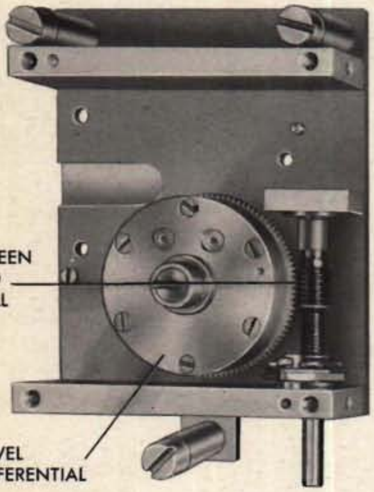
Slipping may be the cause of stalling if the taper pin which secures the worm to the shaft has fallen out.



Erratic timing

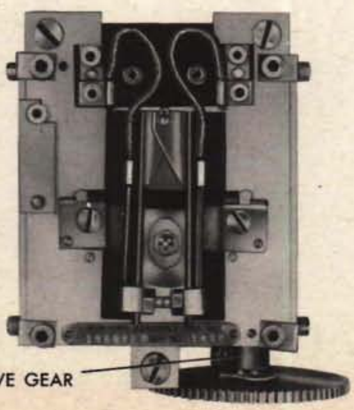
Erratic timing may be due to any of the causes of stalling in the worm shaft assembly.

Erratic timing may be due to intermittent slipping of the friction relief caused by binding in the worm shaft assembly. Insufficient end play, defective bearings, or a tight worm mesh may be the cause of this binding which overloads the friction relief.



Friction relief

Stalling or erratic timing of the time motor regulator may be caused by a loose clamp on the drive gear which will cause the gear to slip on the worm shaft instead of turning it.

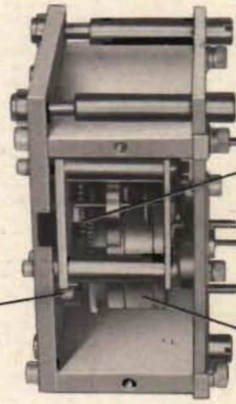


Jewel differential

Stalling

Stalling of the time motor regulator may be caused by jamming or sticking in the jewel differential.

Jamming or sticking may be caused by dirty or damaged bearings, gears, or cam, or by a bent shaft.

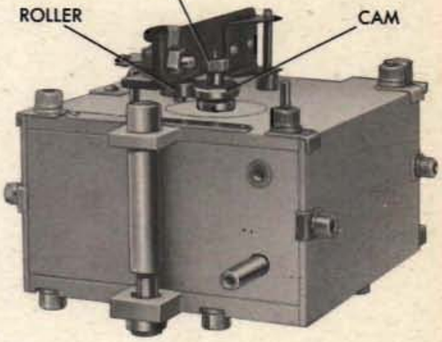


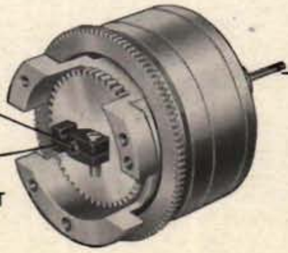
Erratic timing

Erratic timing may be due to any of the causes of stalling or to slipping in the jewel differential.

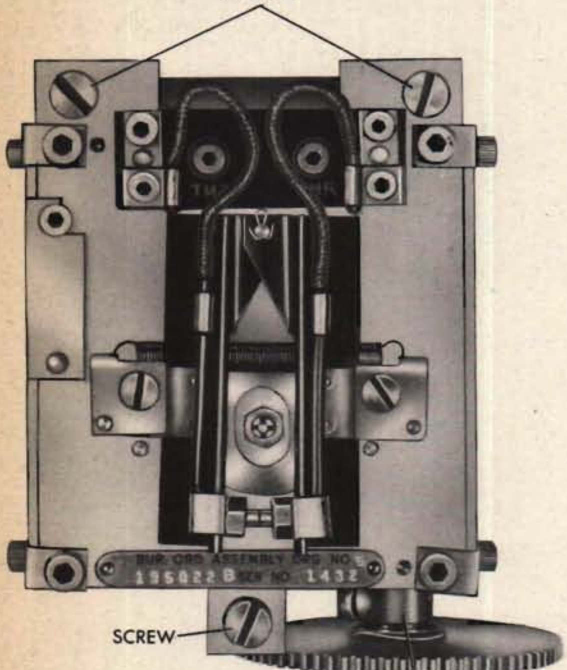
Slipping may be caused by a loose cam nut on the front external shaft or a loose clamp on the rear external shaft.

For repairing the jewel differential, see page 182.





Disassembling the unit



Complete disassembly of the time motor regulator is not necessary for most repairs. If it is necessary, use the assembly drawing as a guide.

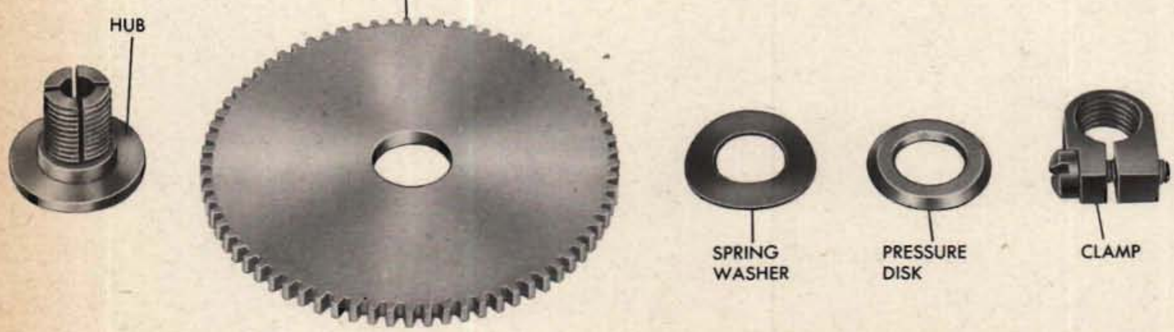
The escapement mechanism and the jewel differential are delicate instruments and should always be handled with extreme care.

Repairs should be made only with the regulator removed from the instrument. It can be taken out easily by unscrewing the three long screws. Then disassemble those subassemblies that require repair.

Disassembling the friction relief

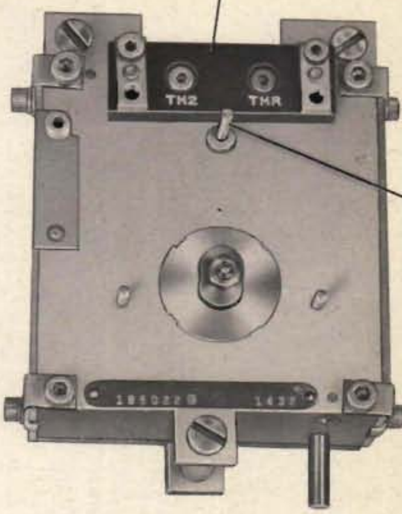
1 Loosen the adjustment clamp and take off the friction relief.

2 To disassemble the friction, screw off the adjustment clamp and separate the parts.

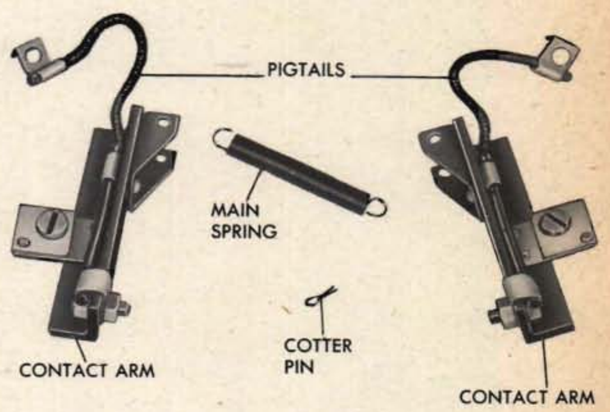


PARTS OF THE FRICTION RELIEF

Disassembling the contact arm assembly



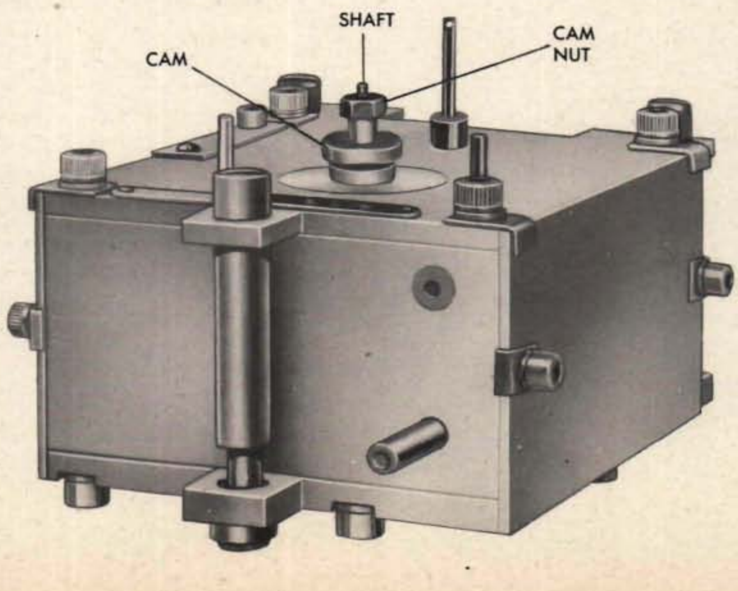
1 Disconnect the pigtails at the terminal block.
2 Remove the mainspring.
3 Remove the cotter pin from the pivot pin.
4 Lift off both contact arms.
5 Remove the terminal block from the case.



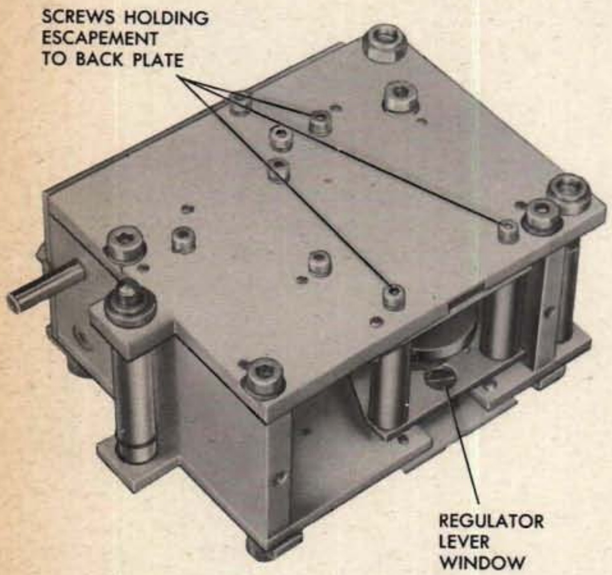
THE CAM is actually a part of the jewel differential, but it should be disassembled with the contact arm assembly.

1 Remove the cam nut. Protect the cam with a wrapping of heavy cardboard or leather and grip it with a pair of pliers while removing the nut. Be extremely careful to avoid bending the shaft.

2 Remove the cam from the shaft.



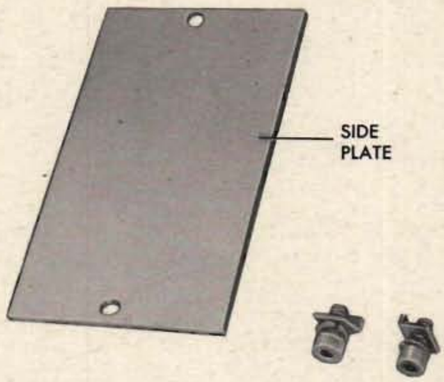
Disassembling the escapement mechanism

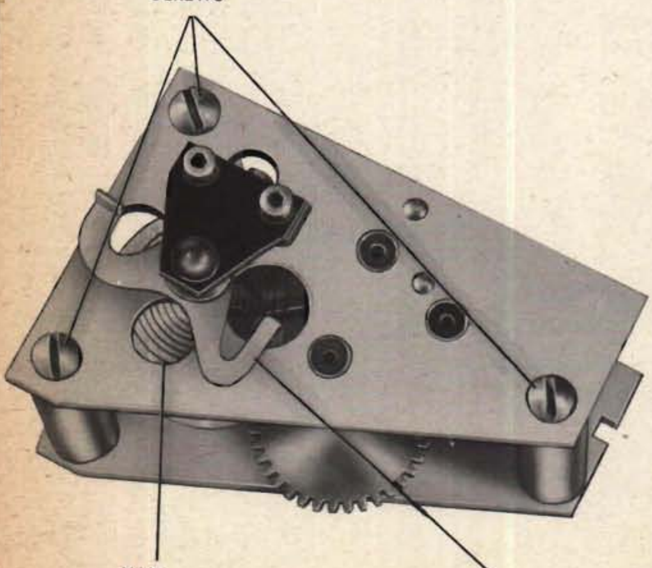


1 Remove the side plate near the regulator lever window.

2 Take out the three small screws holding the escapement mechanism to the back plate.

3 Remove the escapement mechanism from the case.

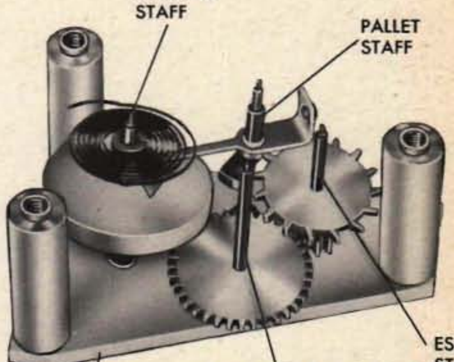




4 Loosen the hairspring anchor clamp. Let the hairspring slip out.

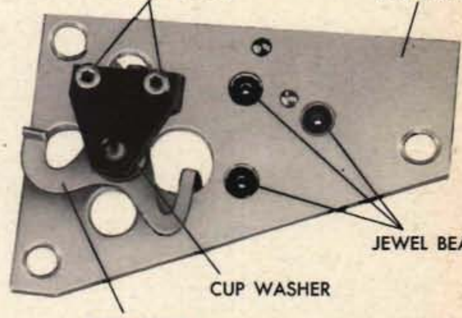
5 Take out the three round-head screws. Lift off the top plate with the regulator lever. Be careful not to damage the hair-spring.

6 Remove the balance staff, input gear staff, escape staff, and pallet staff from the bottom plate.



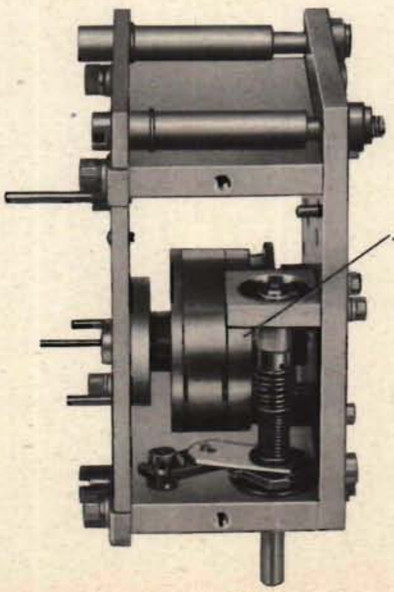
7 To remove the anchor clamp, regulator lever, cup washer, and balance-staff upper bearing, unscrew the two screws that hold the anchor clamp and retainer.

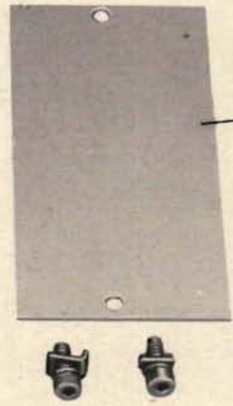
8 To remove the jewel bearings, use a round flat-faced punch that is slightly smaller in diameter than the jewel-bearing mounting hole. Tap the punch lightly, being sure to hold it perpendicular to the plate.

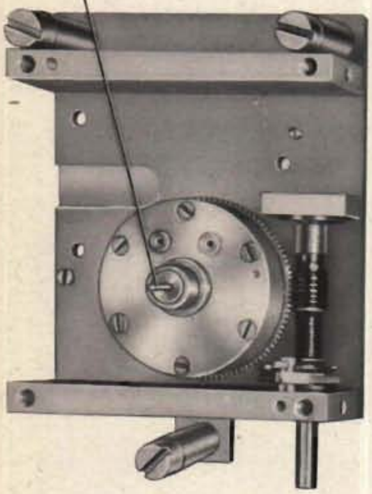


Removing the jewel differential

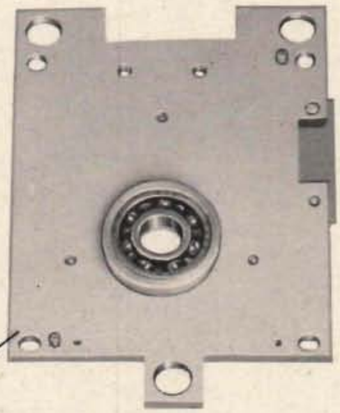
1 Remove the other side plate from the regulator.







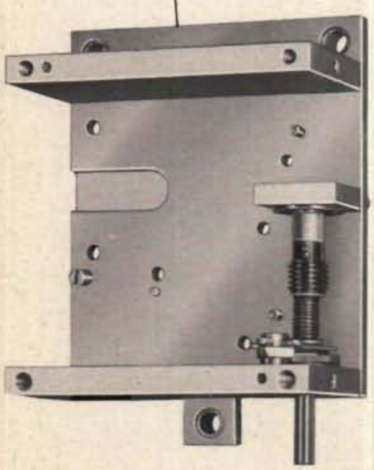
2 Remove the front plate. Be careful not to damage the front external shaft of the differential.

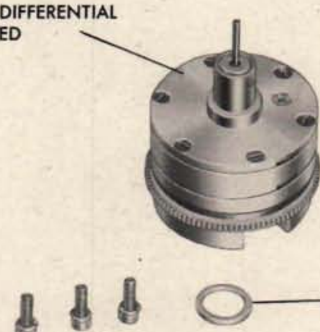


3 Remove the spacer from the differential and tag it.

4 Remove the three screws holding the differential to the back plate.

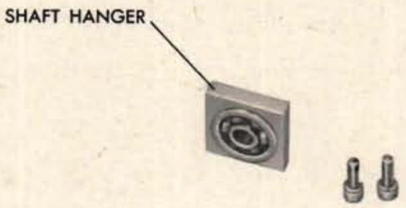
5 Lift out the jewel differential. For disassembly of the jewel differential, refer to the chapter on that unit, page 182.

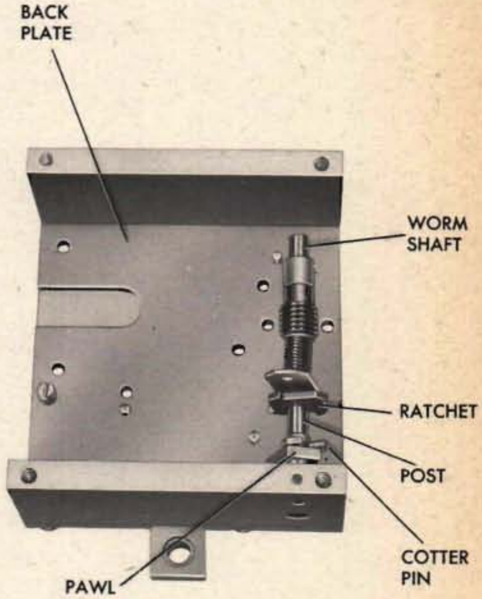




Disassembling the worm shaft assembly

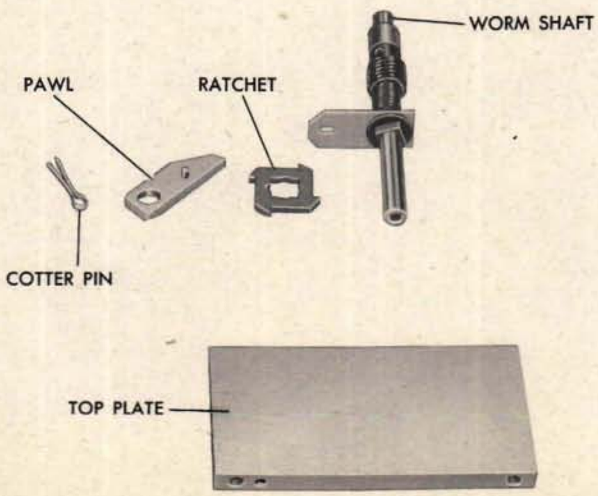
1 Remove the two screws from the worm shaft hanger. Take off the hanger.

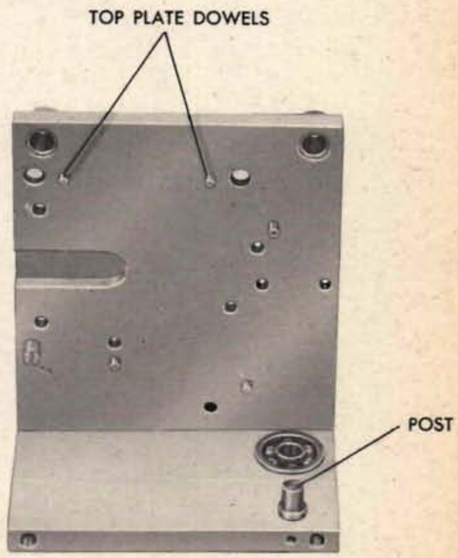




2 Unscrew and remove the top plate. Lift out the worm shaft and ratchet. Separate the ratchet from the shaft. Tag the spacer.

3 Take the cotter pin out of the post. Lift off the pawl.





Repairing the parts

A time motor regulator that requires major repairs should be replaced if another one is available.

Always use the assembly drawing as a guide when making any repair.

Use an approved solvent to remove dirt from bearings and gears.

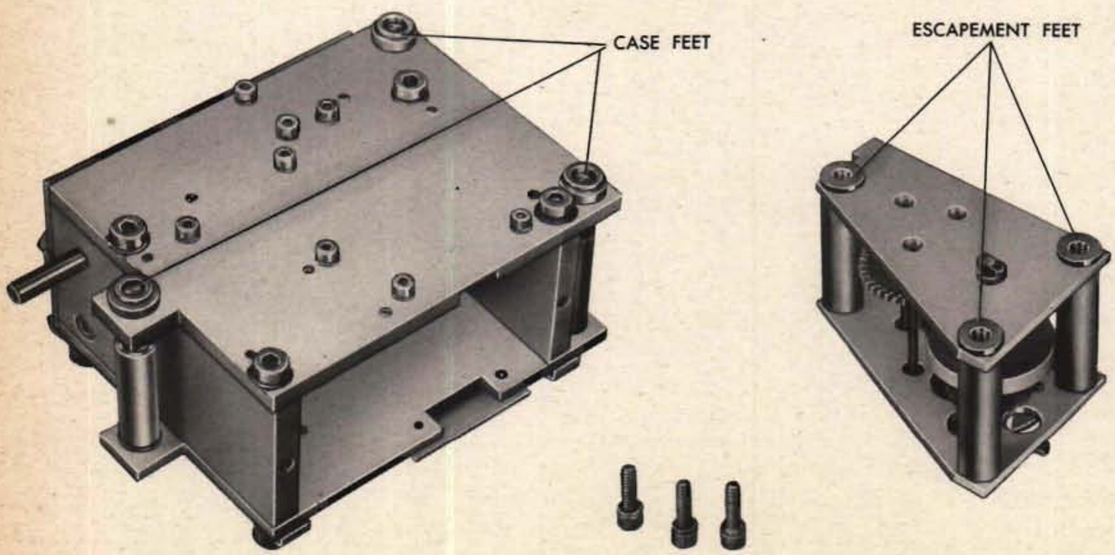
Damaged bearings must be replaced.

Remove burrs from gear teeth with a fine jeweler's file. The escape wheel teeth should be polished.

Remove burrs from pivot pins, spacers, and ends of staffs by polishing.

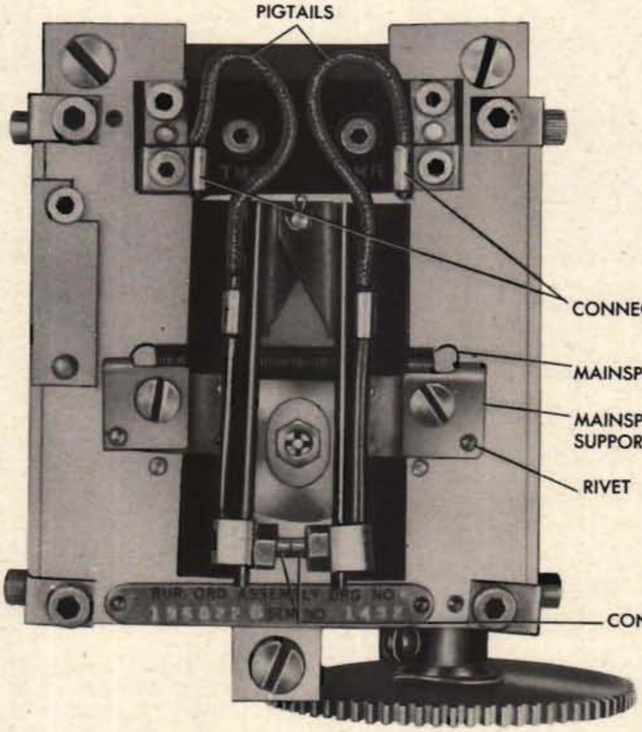
Straighten bent shafts in accordance with instructions on page 69.

If the feet on the case or the escapement are uneven, polish them until they are even. To detect the high spots, move the case or escapement over a flat plate coated with prussian blue. In polishing the feet, make sure that the distance from the input shaft to the plane of the feet is within the allowable limit according to the assembly drawing.



Repairing the contact arm assembly

Rerivet or replace loose mainspring supports. A badly damaged mainspring should be replaced. Be sure to use a spring with the proper number of coils as specified by the assembly drawing.



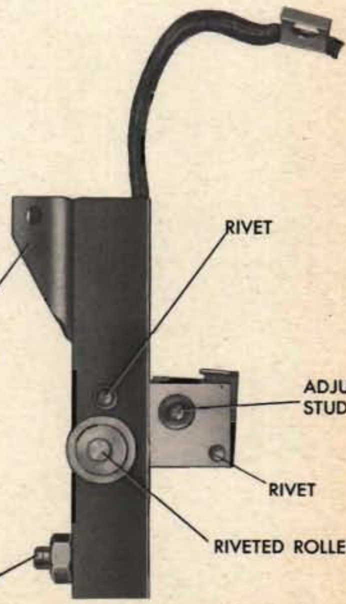
Dirty contacts should be cleaned. Damaged contacts must be replaced.

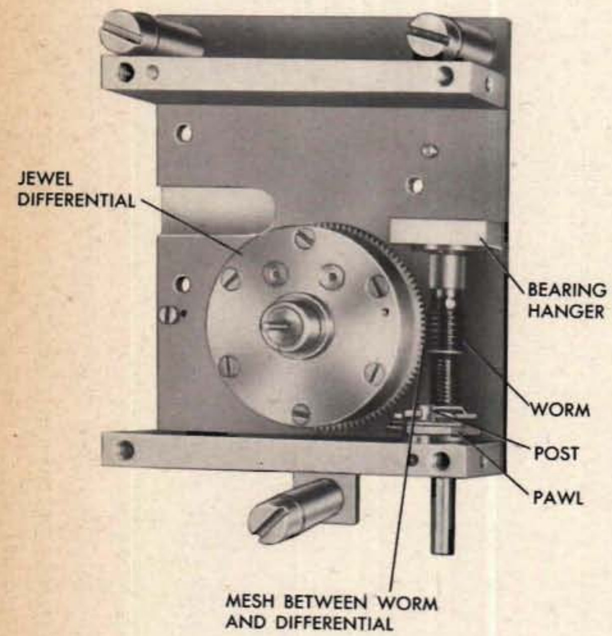
Refer to the chapter *Wiring* for the method of repairing a burned-out pigtail or a broken connection.

Rerivet a loose adjustable stud. After repair, it must be slip-tight so that the tension of the mainspring can be adjusted.

A bent or damaged hinge causing stiffness in the contact arm joint must be straightened and the holes cleared to insure freedom of movement and correct alignment.

A loose roller stud should be tightened by peening the riveted side. If the roller itself is tight or jammed, it should be removed from the stud for cleaning or replacement.





Repairing the worm shaft assembly

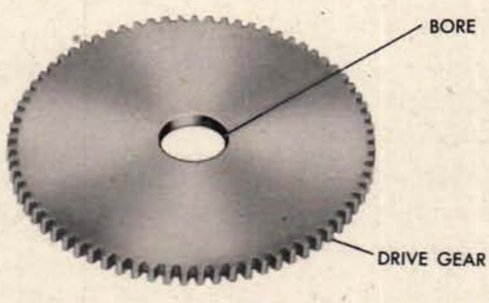
To straighten a bent worm shaft, refer to the instructions for straightening a bent shaft, page 69.

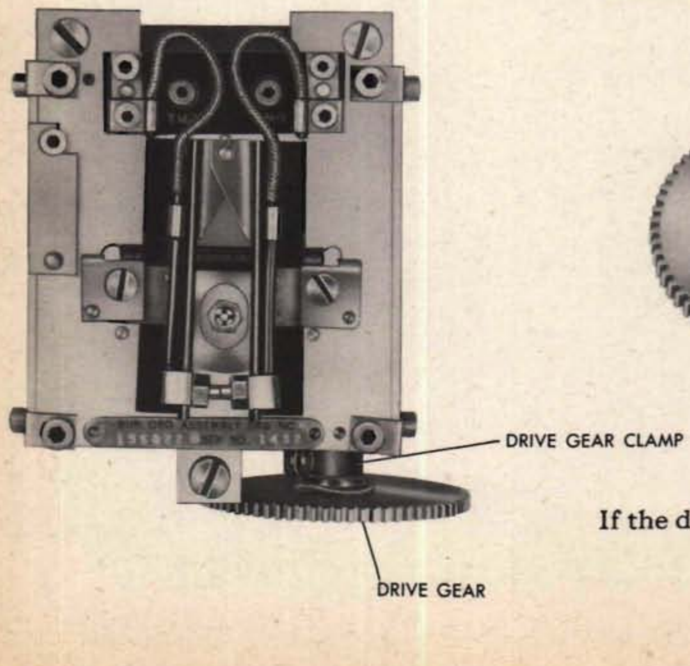
To loosen or tighten the mesh between the worm and differential, move the hanger in accordance with the instructions in *Basic Repair Operations,* page 36.

If the pawl is tight on the post, polish the post to free it.

Repairing the friction relief

If the drive gear is frozen on the hub, polish the bore of the gear.





If the drive gear clamp is damaged, replace it.

Repairing the escapement mechanism

If a replacement is not available, repairs should be made as follows:

Any repair to the escapement mechanism must be handled with extreme care, because it is a very delicate piece of equipment.

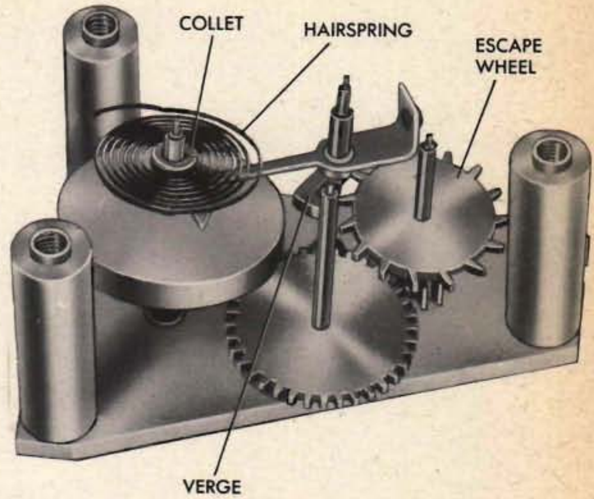
Remove any burrs from the verge or escape wheel by polishing—not stoning.

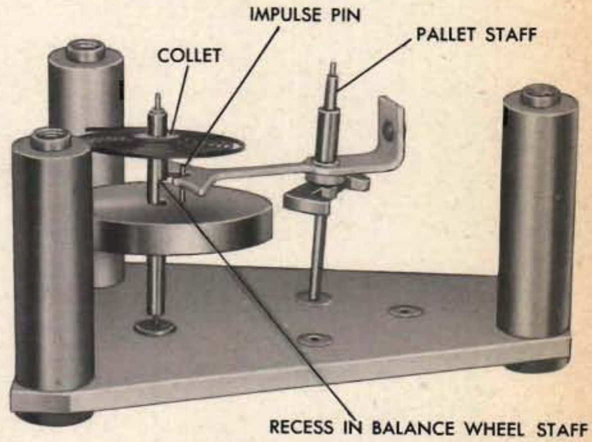
If the regulator lever has been swung to the limit of its adjustment and the escapement is still too slow or too fast, the hairspring should be unclamped and shortened or lengthened, respectively. Whenever this is done, the at-rest position of the balance wheel must be reset by slipping the collet so that the balance staff, the impulse pin, and the pallet staff are in line (see page 492).

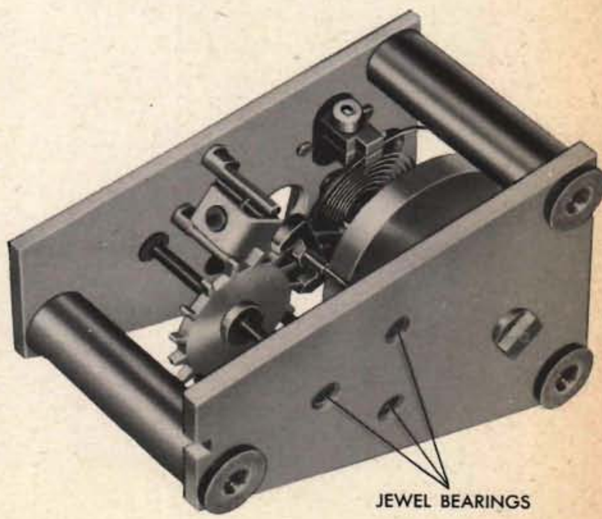
Do not try to repair a damaged hairspring or tighten a loose verge or collet. The entire escapement mechanism should be replaced.

If the impulse pin is not aligned with the recess in the balance wheel staff, firmly grip the staff and slip the balance wheel.

To adjust the end play of a shaft, gently tap the jewel bearings with a round flat-faced punch.



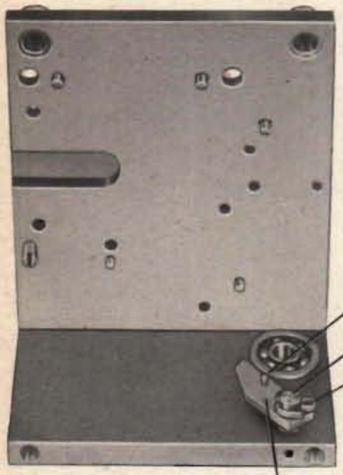




Repairing the jewel differential

For instructions on repairing the jewel differential, refer to page 182.

Reassembling the unit



Reassembly of the various units of the time motor regulator should be carried out with the aid of the assembly drawing. The sub-assemblies should be put together in the following order:

The worm shaft

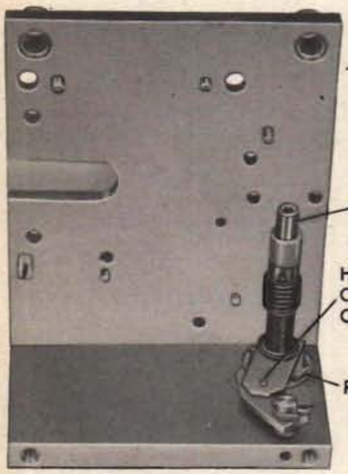
The jewel differential, with the exception of its cam

The escapement mechanism

The cam on the front external shaft of the differential

The contact arm assembly

The friction relief



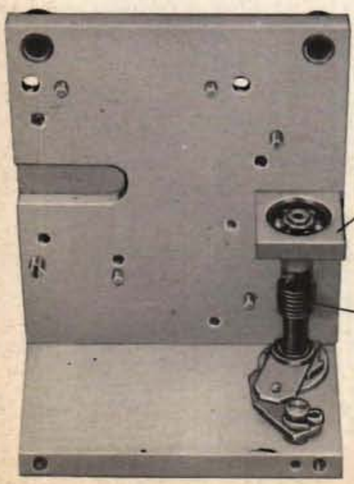
Reassembling the worm shaft

1 Replace the pawl on the post, with the pin on the top. Secure the pawl with the cotter pin.

2 Mount the ratchet on the shaft. With the hole in the arm over the pin on the pawl, put the shaft in the bearing.

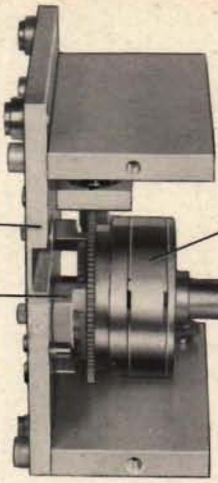
3 Mount the hanger, using screws of the correct length. If the screws are too long, they will "bottom" in the hanger. If they are too short, the threads will be stripped.

The worm gear mesh is adjusted after the jewel differential is installed.

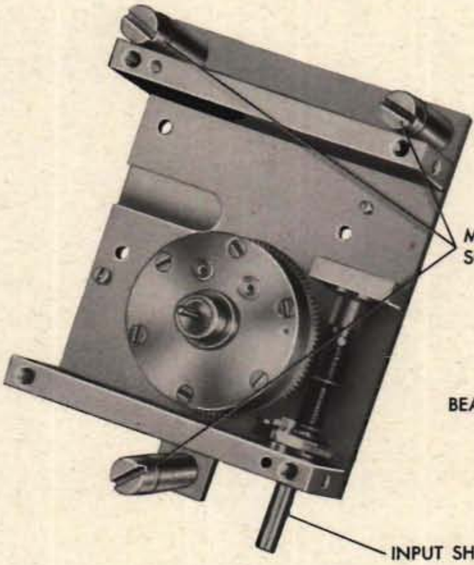


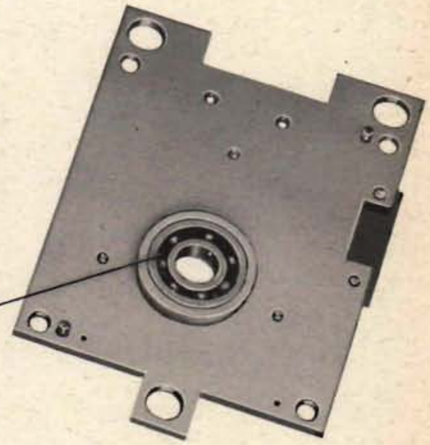
Installing the jewel differential

1 Put the differential in the case with the cutout section of the adapter facing away from the worm shaft. Fit the adapter on the dowels in the back plate and secure it with the screws.

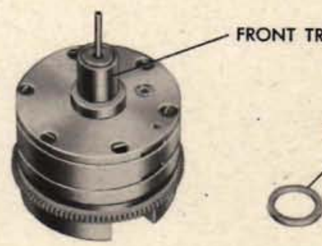


2 Put the three long mounting screws in the case.



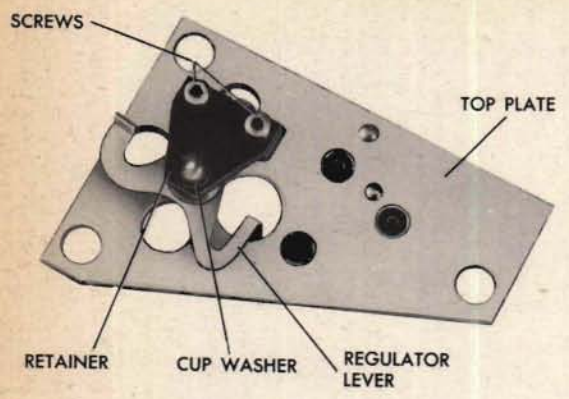


3 Put the spacer over the front trunnion of the differential. Lubricate the bearing in the front plate. Mount the plate on the case.

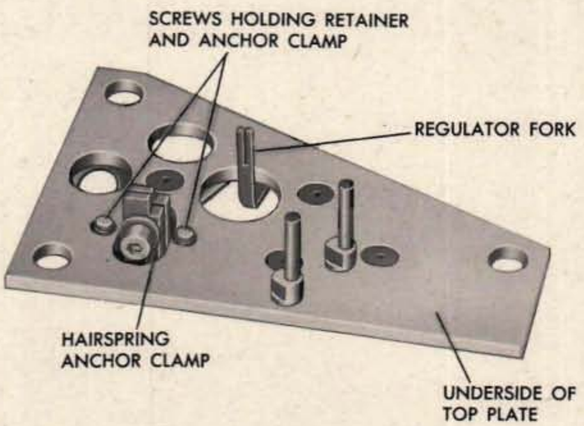


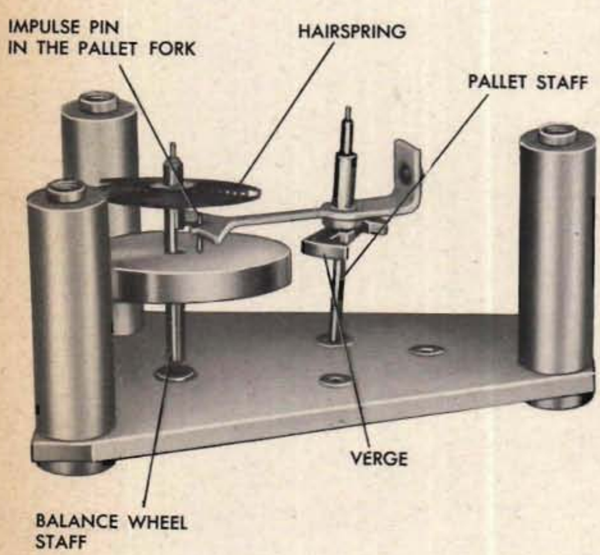
4 Adjust the mesh between the worm and the differential by moving the worm shaft hanger if necessary. Check for freedom of movement by turning the input shaft.

Reassembling the escapement mechanism



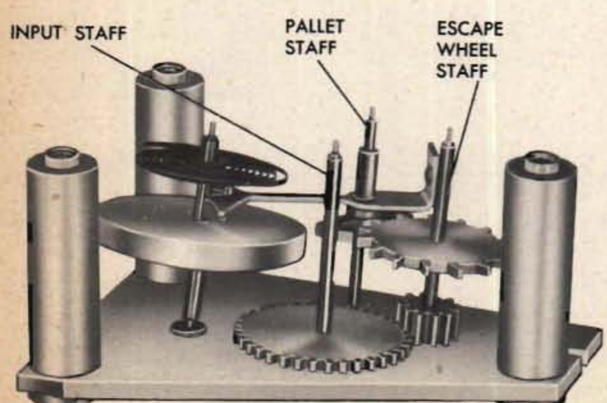
1 Put the regulator lever and cup washer in place on the top plate and insert the balance-staff upper bearing. Put the anchor clamp in place with the clamp screw pointing away from the balance-staff bearing. Add the retainer plate and secure with the two screws.





2 With the hairspring up, seat the balance wheel staff in its jewel bearing in the bottom plate. Use tweezers to avoid damaging the hairspring.

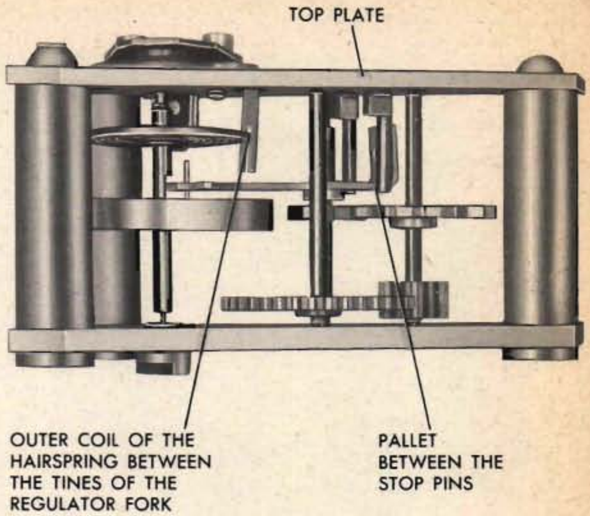
3 Seat the verge end of the pallet staff in its jewel bearing in the bottom plate. The impulse pin must be in the pallet fork.



4 Seat the gear end of the escape wheel staff in its jewel bearing in the bottom plate.

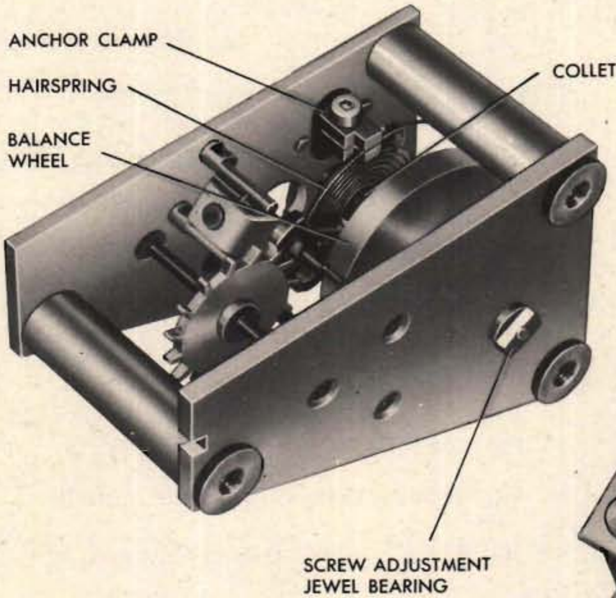
5 Seat the gear end of the input staff in its jewel bearing in the bottom plate.

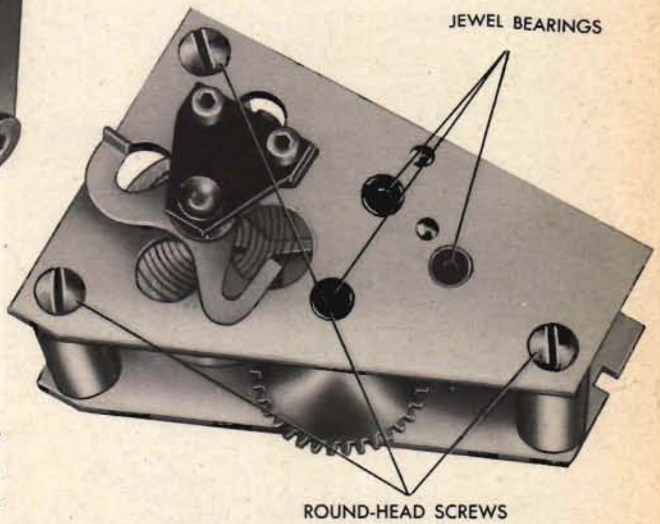
6 Rest the top plate on the posts of the bottom plate. Place the pallet between the stop pins. Place the outer coil of the hairspring between the tines of the regulator fork.



7 Seat the shafts in the jewel bearings of the top plate. Secure the plate by means of the round-head screws that go into the posts.

8 Adjust the end play of the balance wheel staff by turning the screw adjustment jewel bearing.

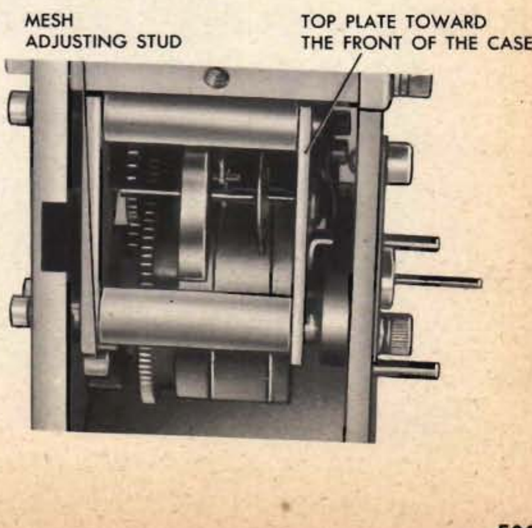




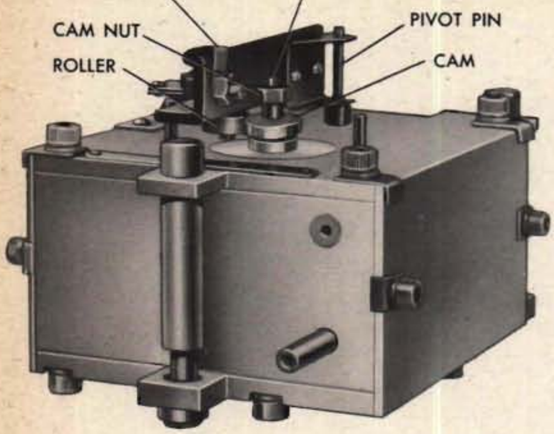
9 Place the end of the hairspring in the anchor clamp and tighten the clamp. Slip the collet to line up the impulse pin. The hairspring may have to be adjusted later to improve the timing.

10 Bench check the escapement mechanism. See page 511.

11 Place the escapement mechanism in the case with the top plate toward the front of the case. Check the mesh between the escapement and the differential. If any adjustment is required, turn the mesh adjusting stud.



12 Screw the side plates of the case in place.

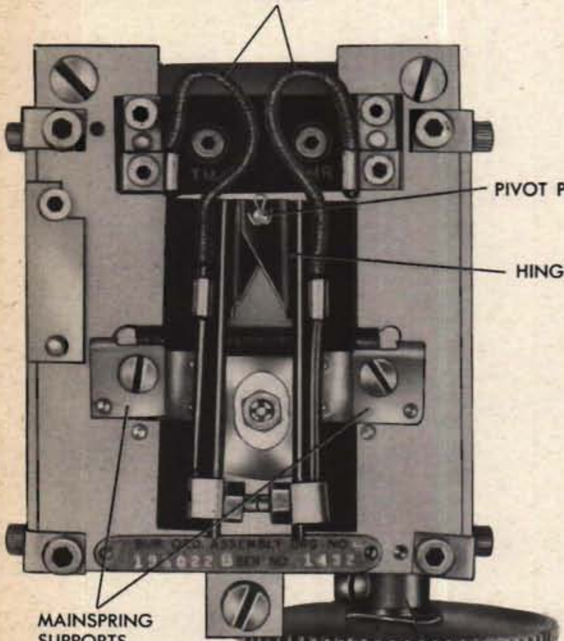


Reassembling the cam

1 Slide the cam onto the front external shaft of the differential.

2 Put one of the contact arms on the pivot pin and adjust the height of the cam to the contact arm roller.

3 Place the cam nut on the cam and tighten it. Be very careful not to bend the shaft.



Reassembling the contact arms

1 Screw the terminal block in place with the insulation strip under it.

2 Slide the hinges of the contact arms together and slip the hinges over the pivot pin. Secure the hinges by putting the cotter pin through the pivot pin. Bend the ends of the cotter pin.

3 Slip the ends of the mainspring through the holes in the mainspring supports.

4 Connect the pigtails to the terminal block.

Reassembling the friction relief

1 Assemble the friction relief by slipping the gear over the hub. Put the spring washer over the hub, and the pressure disk on top of the spring washer. Put the clamp on the hub.

2 Slip the hub over the input shaft of the regulator and tighten the clamp.

Bench checking the escapement mechanism

1 The balance wheel staff, the impulse pin, and the pallet staff must be aligned when the escapement is at rest.

2 The banking pins must prevent the verge from bottoming in the escape wheel but should permit 0.01 to 0.02-inch movement of pallet tip against balance staff when the balance staff is rotated to its extreme positions.

3 With the escapement at rest, the regulator fork must not touch the hairspring at any position.

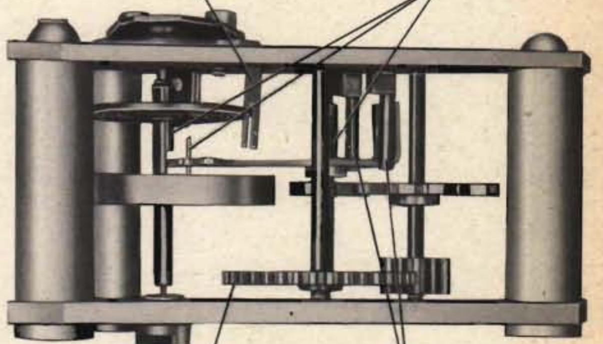
4 The impulse pin must be centered opposite the recess in the balance wheel staff.

5 Spacing between the turns of the hairspring must be uniform.

6 The coils of the hairspring must not at any time touch each other or any object except the regulator fork.

7 The escapement must start with slight pressure on the input gear.

8 End shake on all staffs should be between 0.004 and 0.008 inch.



Bench checking the time motor regulator

1 The friction relief must slip when the gear is turned clockwise.

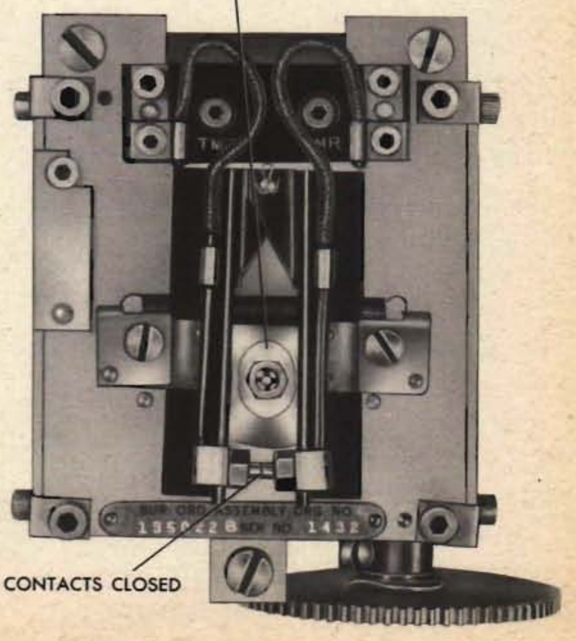
2 Eccentric studs and the cam nut must be tight.

3 The contact arms must move freely on the pivot pin. The contact arm rollers must be free.

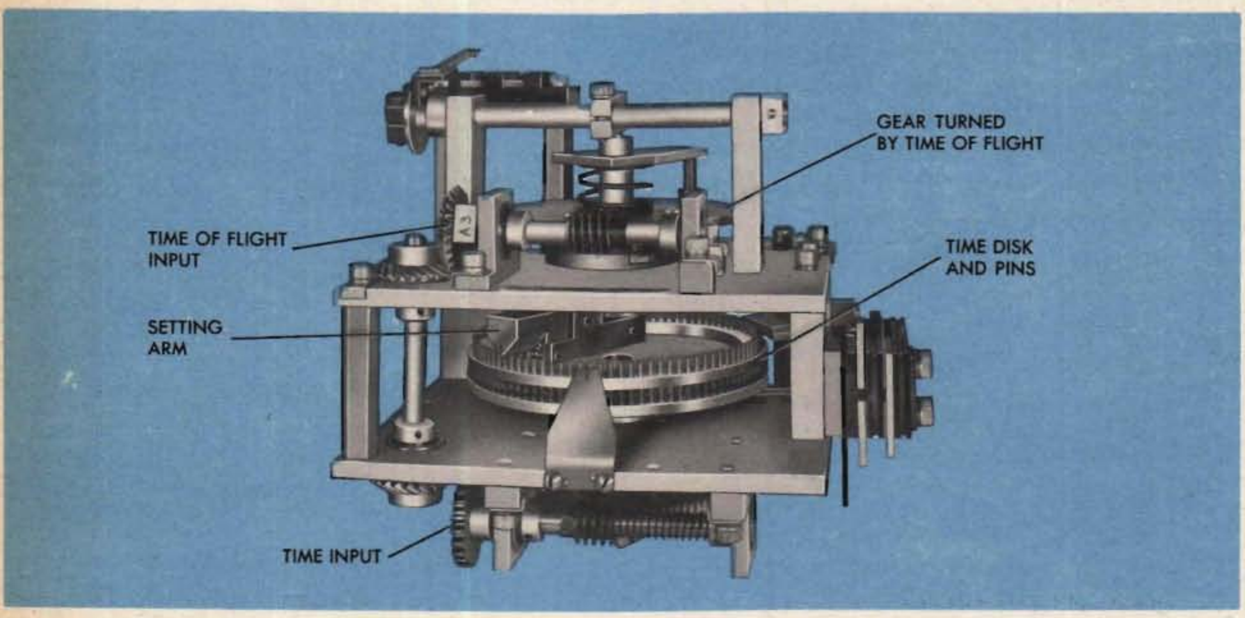
4 The contacts should open when the cam is approximately 30° from the vertical.

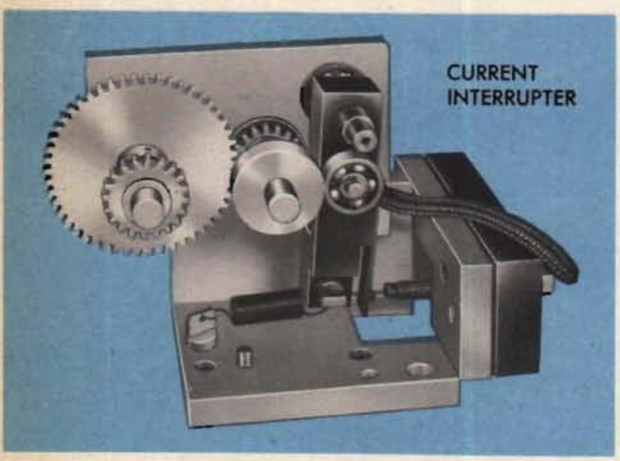
5 Test the pigtail wiring and contacts for continuity.
CAUTION: Never apply 115-volt A.C. to the terminals of the motor regulator. It will burn out the pigtails.

6 Install the time motor regulator in the instrument and run the time motor regulator test. As a guide for timing and adjusting, see OP 1140, page 216.

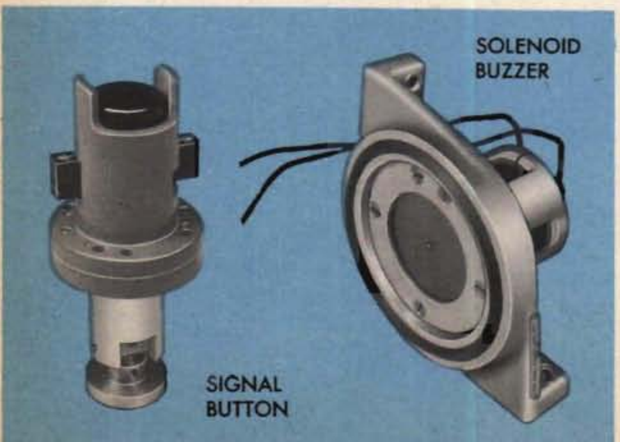


TIME OF FLIGHT MECHANISM





Units making up the time of flight signal system are a signal mechanism, current interrupter, signal button, and solenoid buzzers. Each of these units is mounted separately. The main parts of the signal mechanism are a setting arm, turned by the time of flight input, and a time disk containing 96 regularly spaced pins, turned by the time input. The time of flight mechanism operates in conjunction with the signal button and the current interrupter to produce signals in buzzers that are connected in parallel. One buzzer is in the instrument. Others are located at the observers' stations.



Complete disassembly is not always necessary to repair a unit of the system. Minor repairs may be made while a unit is intact or partially disassembled. Each unit of the system can be removed separately. If a unit must be removed, consult the instrument OP for instructions.

SIGNAL MECHANISM

Typical symptoms

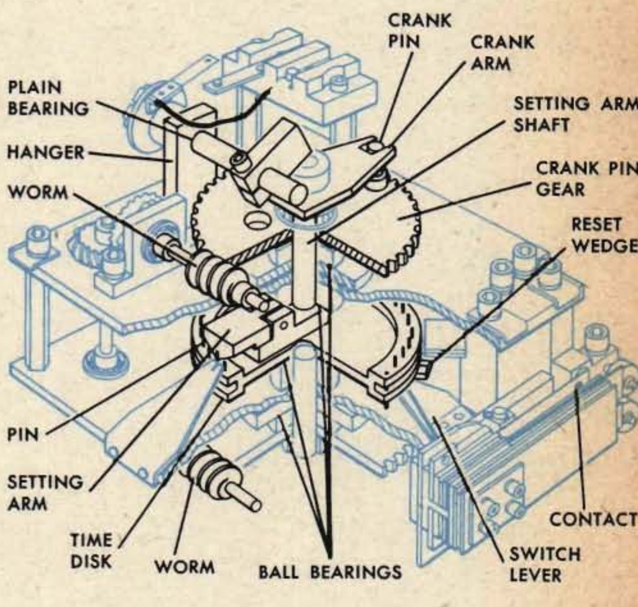
If a test analysis indicates that the time of flight mechanism is not operating properly, first check the circuit for continuity and be sure it is supplied with 115-volt A.C. Also make sure that all adjustments are correctly made. Then look for one or more of the following typical symptoms:

JAMMING: One or more of the gears or other moving parts cannot be moved by hand. *Moving parts include the 96 pins in the time disk.*

STICKING: Gears or other moving parts resist motion or move sluggishly.

EXCESSIVE LOST MOTION: There is too much play between gears or other moving parts.

ELECTRICAL TROUBLE: Contacts do not open or close properly.

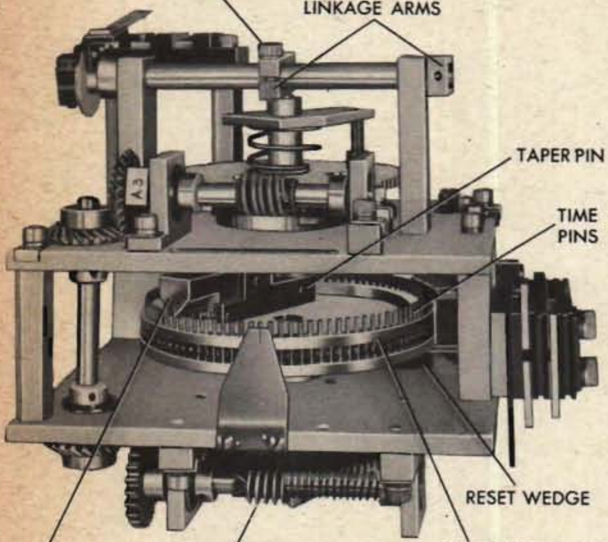


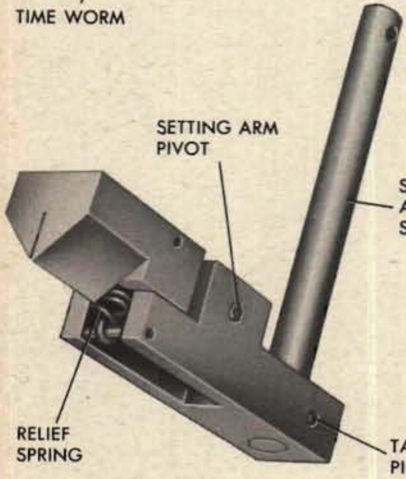
Locating the cause

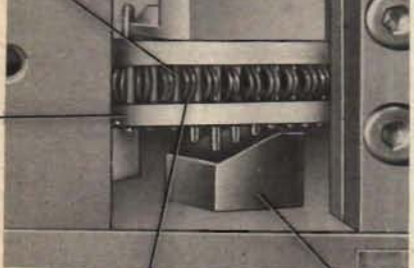
Jamming or sticking

Jamming or sticking may be due to dirty or damaged gear teeth, bearings, or pins, or to a dirty or damaged crank arm, crank pin, setting arm, wedge and spring, worm, or worm gear. A bent shaft in either worm shaft line will cause binding of the worm at one point and excessive lost motion at another.

If the linkage cannot be moved by hand or resists moving, the plain bearings may be dirty or damaged, the hangers may be improperly positioned, the setting arm shaft may be damaged or dirty, or the crank pin may be damaged.







If the linkage can be moved by hand but none of the pins are pushed down when the linkage is moved, the linkage clamping screw may be loose; the taper pin holding the setting arm to the shaft may be missing; the relief spring in the setting arm may be weak, unhooked, or missing; one or more of the time pins may be frozen in the time disk; or the setting arm may be frozen to the pivot in a slightly elevated position.

A time pin may become damaged or bent by jamming against the wrong side of the reset wedge, if the time worm is frozen to its shaft and the time line is run backward for any reason.

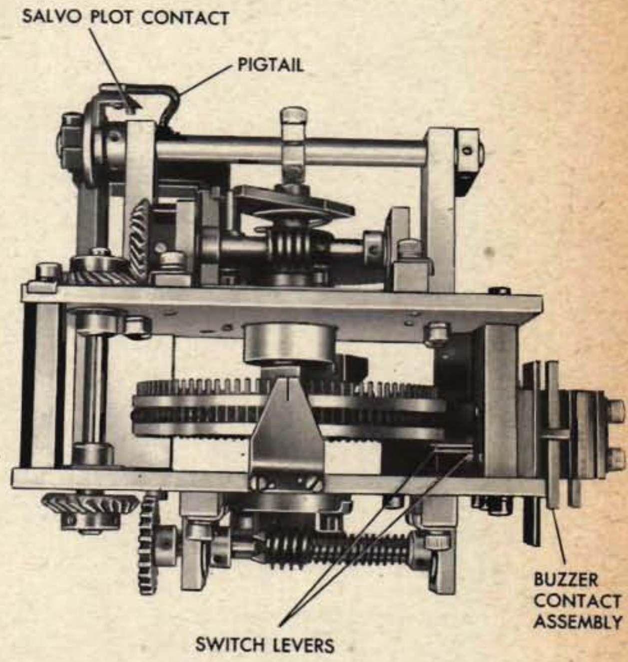
Excessive lost motion

Excessive lost motion between a time pin and its hole in the time disk may be due to enlargement of the hole caused by a bent pin. Pins may drop if the coil spring holding them is damaged.

Excessive lost motion may also be caused by improperly located hangers, by bent shafts, or by worn gears.

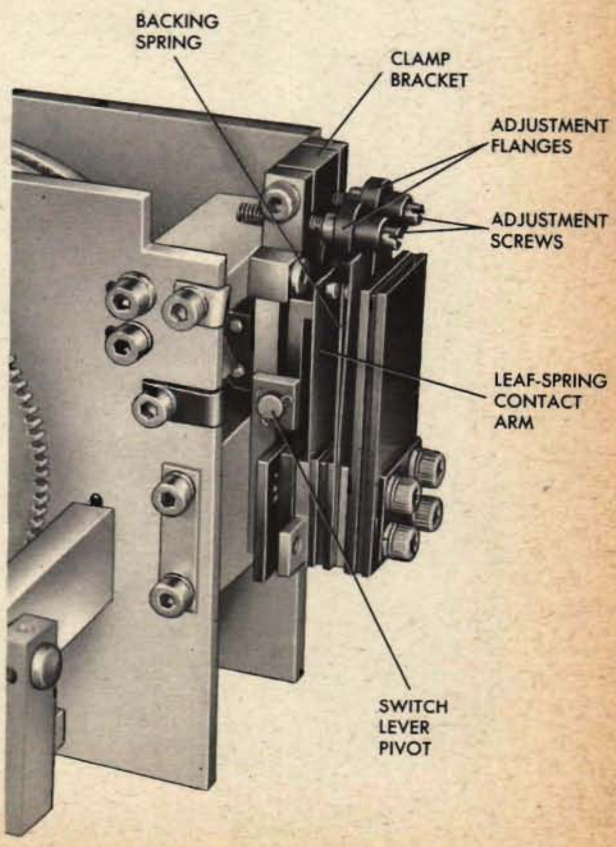
Electrical trouble

Electrical trouble in the time of flight signal system may be due to a casualty in the buzzer contact assembly attached to the time of flight mechanism.



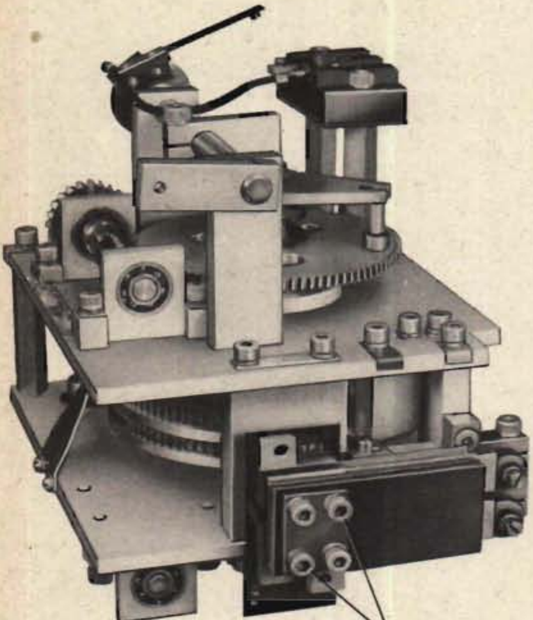
If the buzzer circuit is grounded, the trouble may be due to a bent contact which touches a metallic part of the mechanism. In reassembling the buzzer contacts, make sure the mounting screw bushings are replaced correctly; otherwise, the contact arms may ground against the screws.

Continuously sounding buzzers may indicate that the buzzer contacts are held closed. The contacts may be held closed if the switch lever pivot is jammed, hindering the spring action of the leaf-spring contact arm, if the contact is caught in the hole in the backing strip, or if a leaf-spring contact arm is bent out of shape.



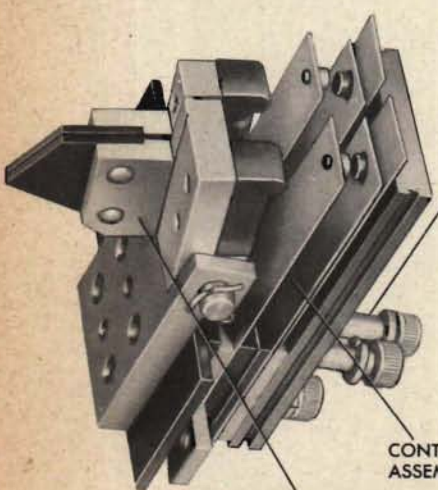
If the buzzer fails to sound, probably the adjustment screws are backed out too far. Consult the instrument OP for instructions on adjusting the contact gap. Make sure that the clamp bracket holds BOTH adjustment screws. An open in the time of flight mechanism buzzer circuit may also be due to dirty contacts or a broken lead.

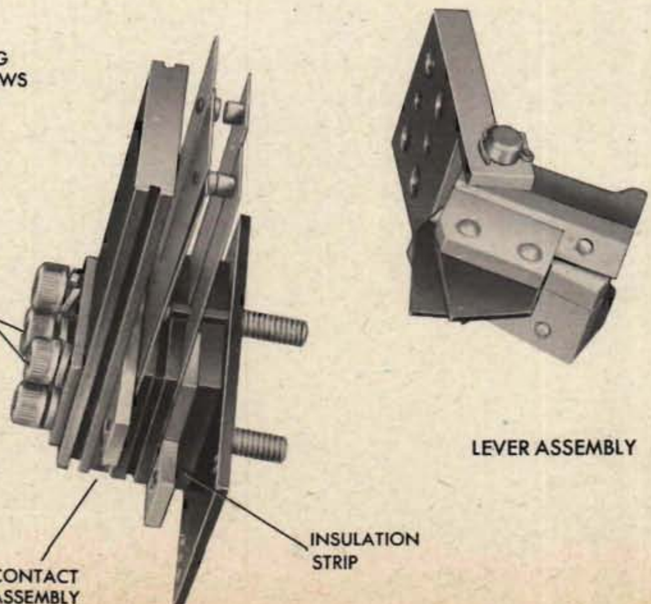
Disassembling the signal mechanism



1 Remove the two long screws in the contact assembly and lift off the contact and lever assemblies.

2 Loosen the short screws until the lever assembly is separated from the contact assembly. Do not take the screws out completely, because they hold the contact assembly together. The stamped insulation strip is part of the contact assembly.



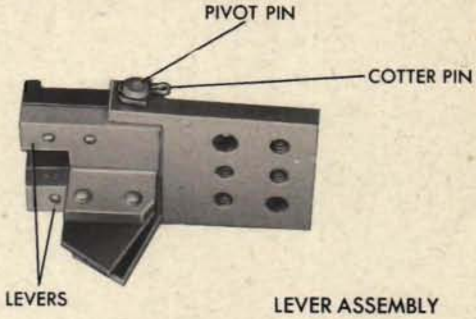


3 Remove the cotter pin in the lever assembly, slide out the pivot pin, and separate the parts. Tag the spacer.

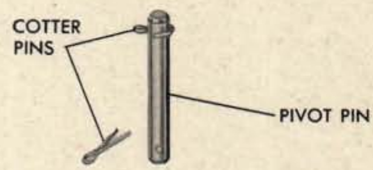
4 Take out the two screws which hold each bakelite shoe to its lever.

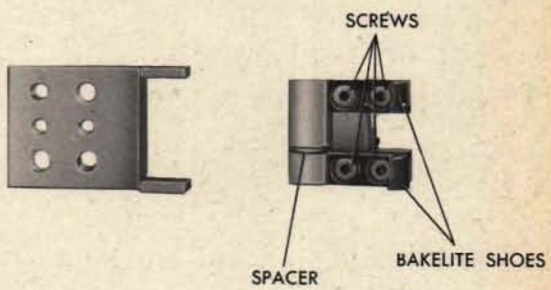
5 Remove the two short screws remaining in the contact assembly and lift off the steel screw plate. The four insulation bushings tend to hold the other parts in position. If necessary, draw a sketch of the parts and the assembly order as an aid in reassembly.

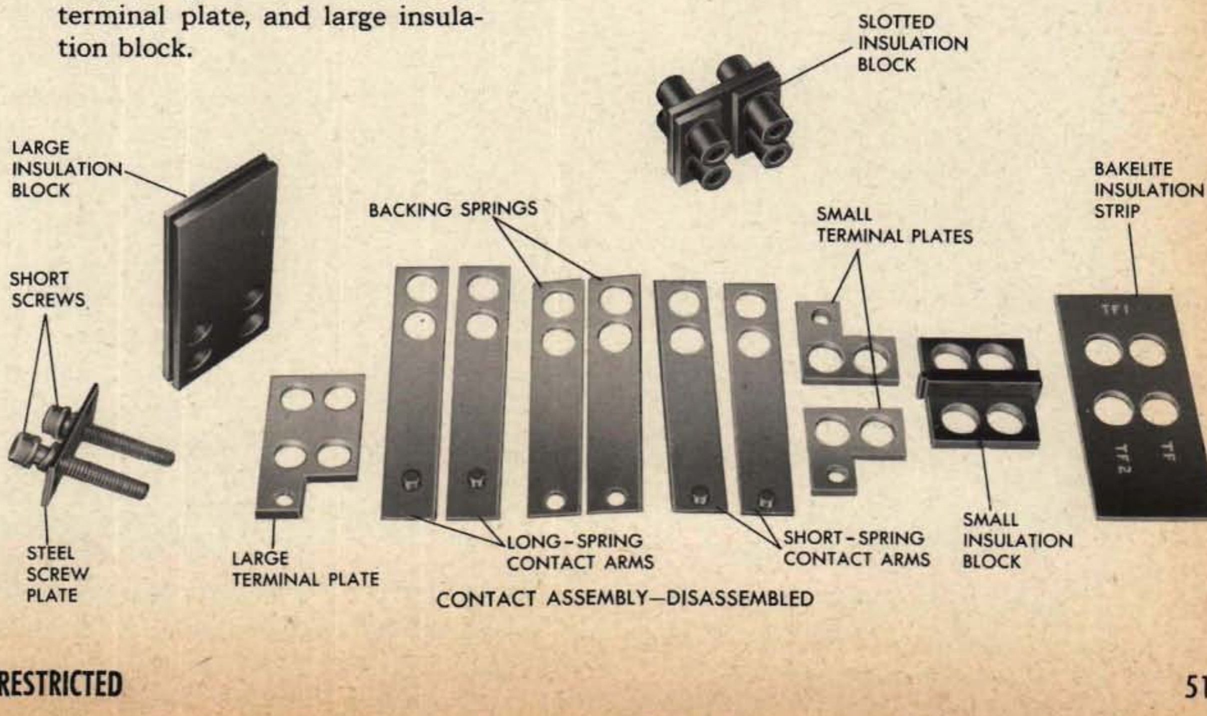
The parts of the contact assembly now to be disassembled are in order: bakelite insulation strip, small insulation block, two small terminal plates, two short-spring contact arms, slotted insulation block, two backing strips, two long-spring contact arms, large terminal plate, and large insulation block.



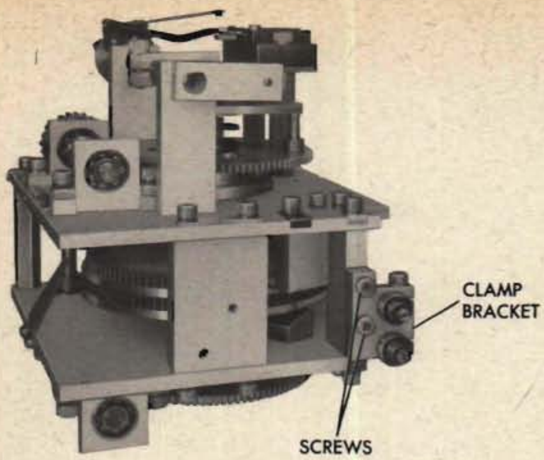
LEVER ASSEMBLY

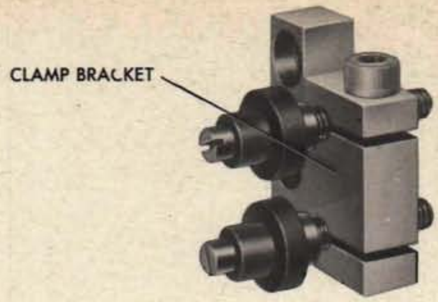




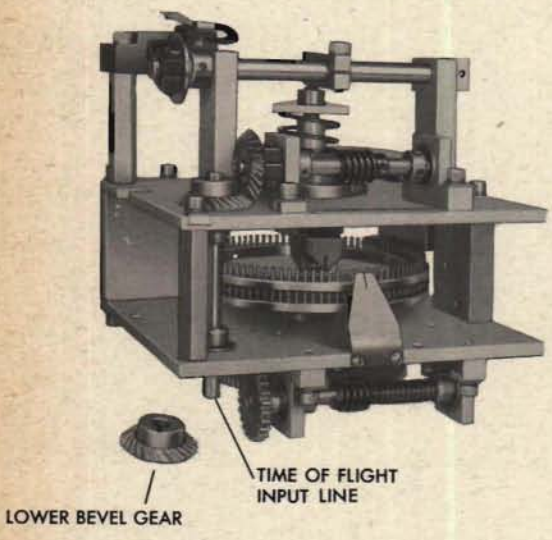


CONTACT ASSEMBLY—DISASSEMBLED

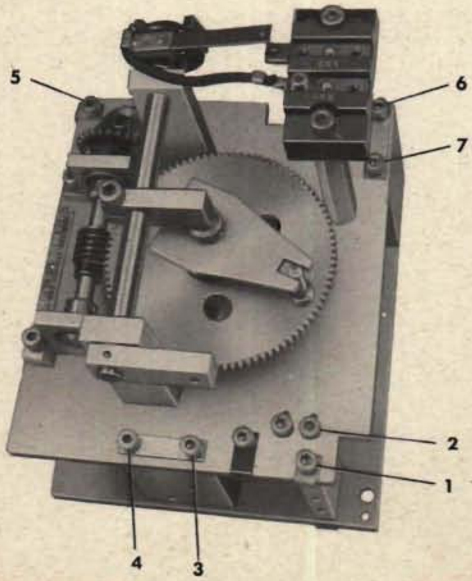




6 Remove the clamp bracket with the adjustment flanges by removing the two screws.

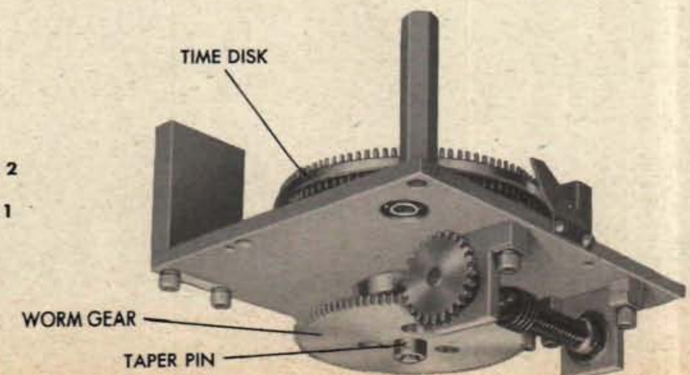


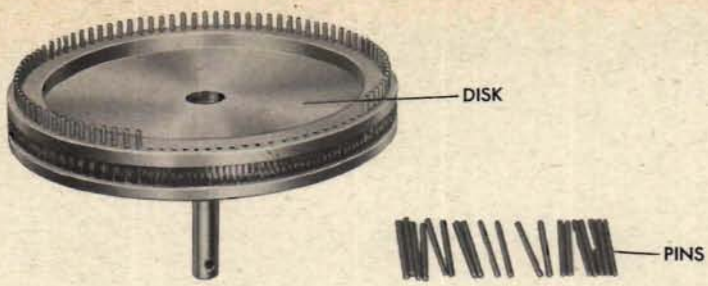
7 Drive the taper pin out of the lower bevel gear on the time of flight input line and remove the gear.



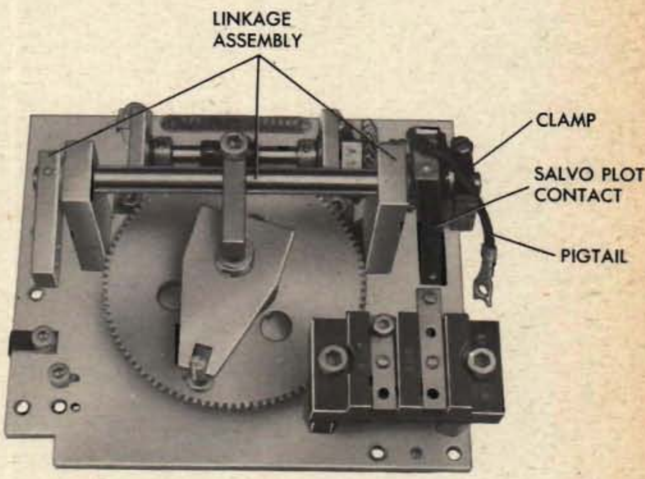
8 Take the seven screws out of the top section and separate the top section from the bottom section.

9 In the lower section, remove the time disk by driving the taper pin out of the worm gear hub on the time disk shaft.





10 Push the pins out of the disk *by hand* (tools may burr them). Be careful not to pull the spring loose from the time disk.

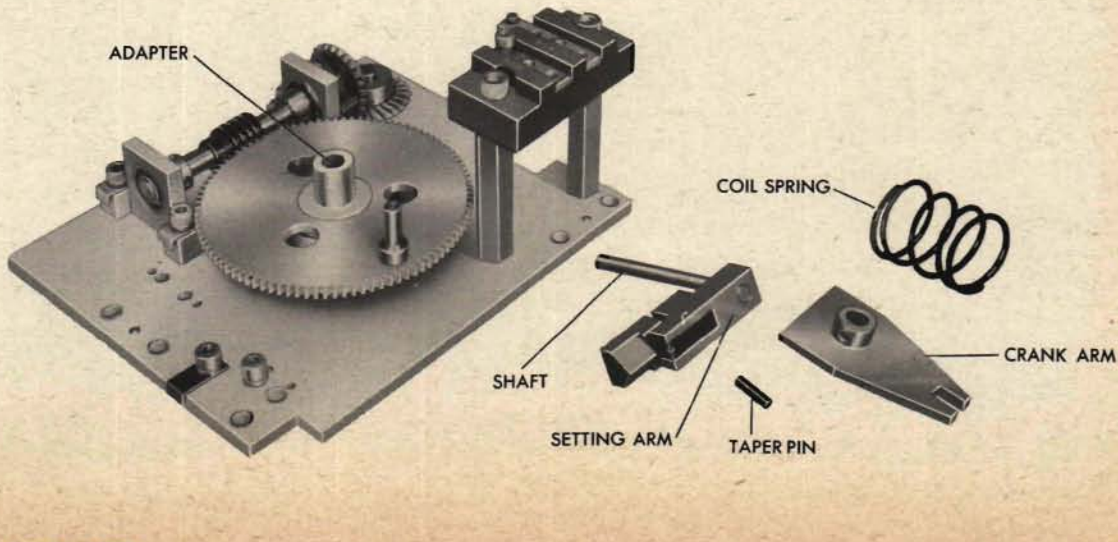


11 In the upper section, remove the salvo plot contact by disconnecting the pigtail at the terminal and opening the clamp. Tag the spacer.

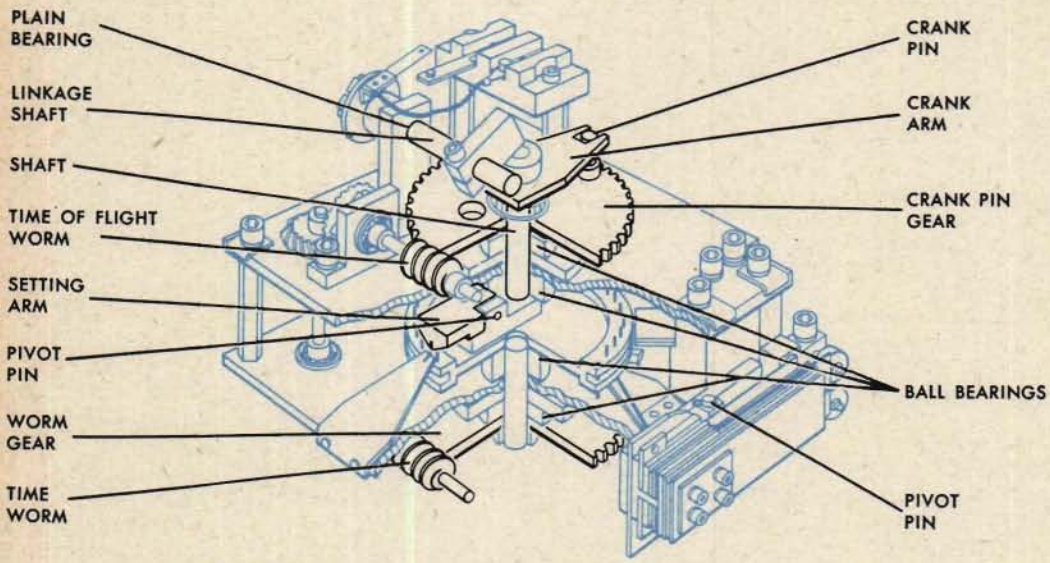
12 Remove the linkage assembly by taking out the four screws which secure the hangers to the plate.

13 Drive the taper pin out of the crank arm and remove the crank arm and the coil spring.

14 Slide the setting arm and shaft out of the adapter.

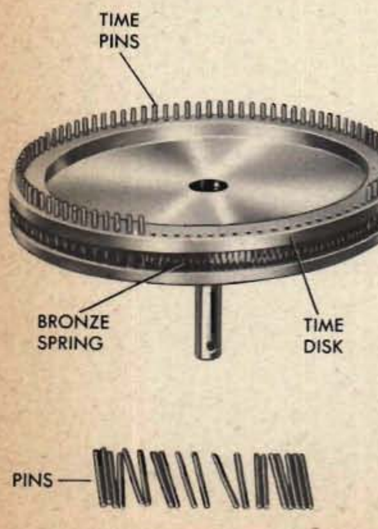


Repairing the signal mechanism



Cleaning, repairing or replacing moving parts

The moving parts are gears, bearings, pivot pins, worms, the setting arm shaft, time disk, setting arm, crank arm, crank pin, and the linkage shaft. Parts should be cleaned with an approved solvent. Remove burrs by polishing, being careful not to remove excessive amounts of metal. After repairing, apply an approved lubricant to the parts.



Repairing or replacing the time disk

Polish a time pin that is burred. If a pin is too small or the hole in the time disk is too large, an oversize pin can be used. Consult the assembly drawing for the size and material of the pin.

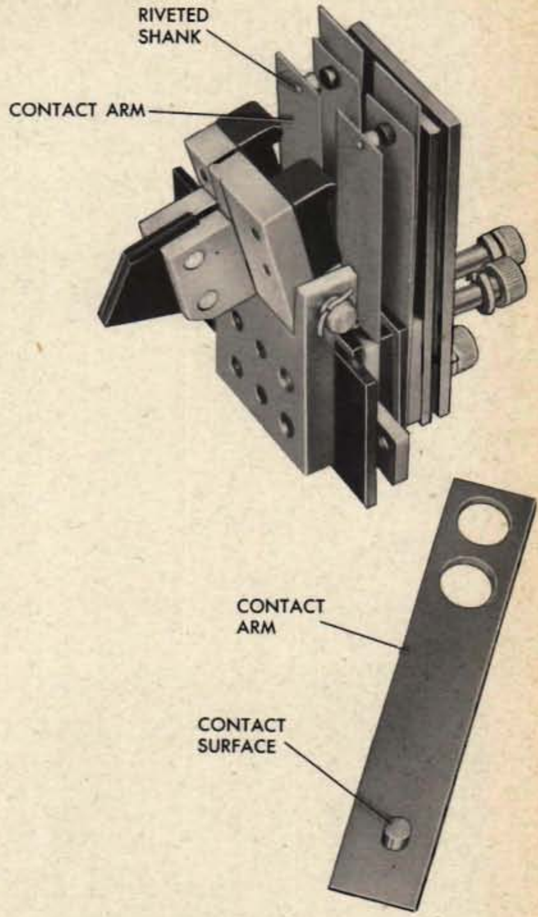
If the time disk is so badly damaged that a large number of the 96 pins have to be replaced, use a new disk.

A bent pin may jam in the time disk. Check its straightness by rolling it under a finger on a flat surface. Pins are difficult to straighten; hence it is desirable to replace them. Lubricate the pins before reassembly.

If the bronze spring in the time disk should become slightly distorted, it can usually be reshaped by hand. A badly damaged spring should be replaced.

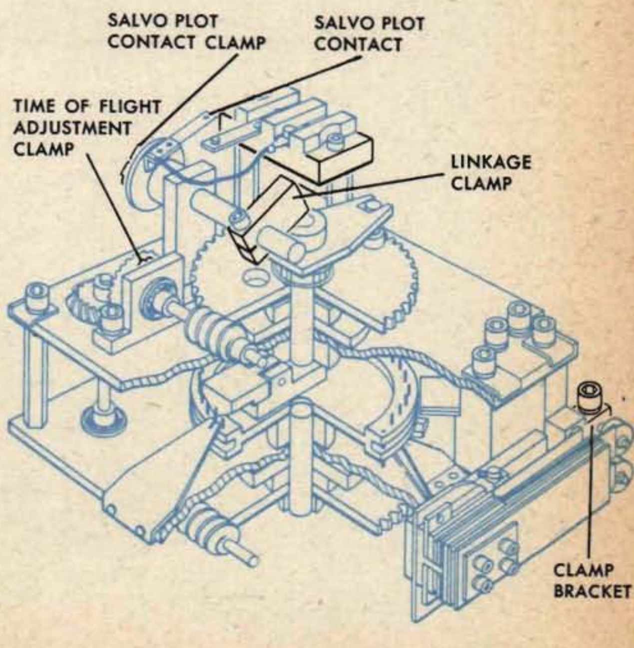
Cleaning and repairing contacts

Remove the contact arm before cleaning or repairing it to avoid bending it out of shape. If the contacts are pitted or dirty, polish them down to a smooth finish with a fine oil stone, or very fine abrasive paper. Keep the contact surface square while polishing. Never use an abrasive coarse enough to leave visible scratches. Scratches favor arcing which tends to pit and dirty the contacts anew.



Sometimes a high-resistance circuit will result if the riveted shank has become loose in the leaf-spring contact arm. Usually this condition can be repaired by reriveting the shank.

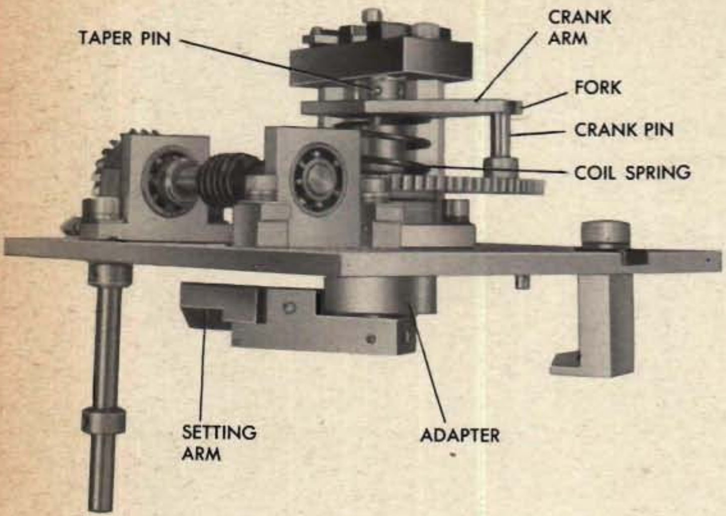
Clamp adjustments



Clamps that have slipped or clamps that have been improperly adjusted are a main source of trouble in the signal mechanism. There are four clamps on the mechanism unit: one on the linkage, one on the salvo plot contact, another on the time of flight input shaft, and the clamp bracket which holds the contact adjustment screws in position. One or more of the three regular adjustment clamps may be slipping because the clamp is not well fitted to the shaft. The remedy will be found in the chapter on *Shaft Lines,* page 92.

In order to determine whether a clamp is properly adjusted or to readjust a clamp, refer to the instrument OP.

Reassembling the signal mechanism

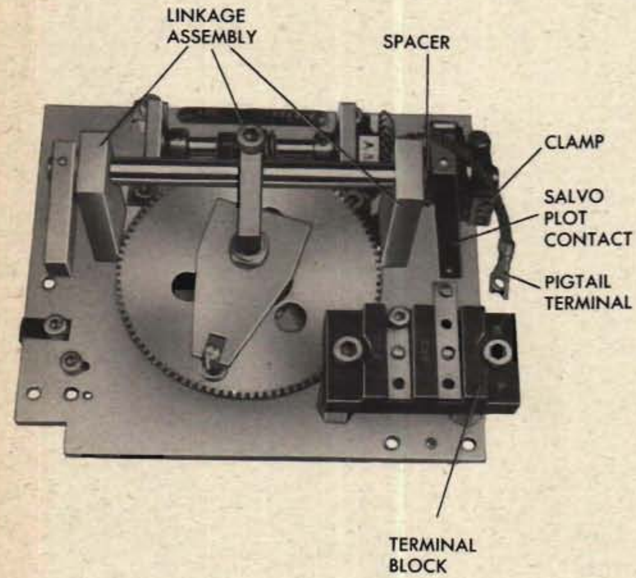


Be sure to lubricate the parts before reassembly.

1 Replace the setting arm and shaft in the adapter in the upper section. Lubricate the shaft with an approved lubricant.

2 Replace the coil spring on the shaft.

3 Mount the crank arm on the shaft with the crank pin in the fork. Pin the arm to the shaft.

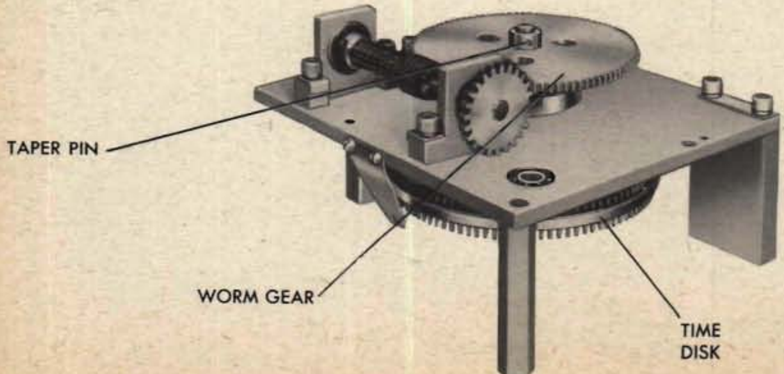


4 Replace the linkage assembly on the upper section. Space the hangers properly so that the shaft moves freely in the hangers.

5 Replace the spacer and the salvo plot contact and clamp. *Do not connect the pigtail to the terminal block.*

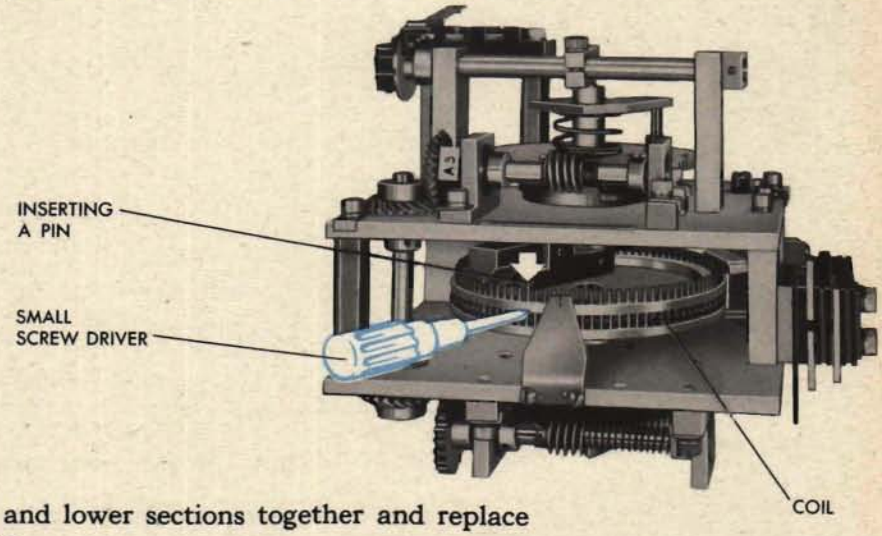
6 Replace the time disk in the adapter in the lower section.

7 Pin the worm gear to the shaft.

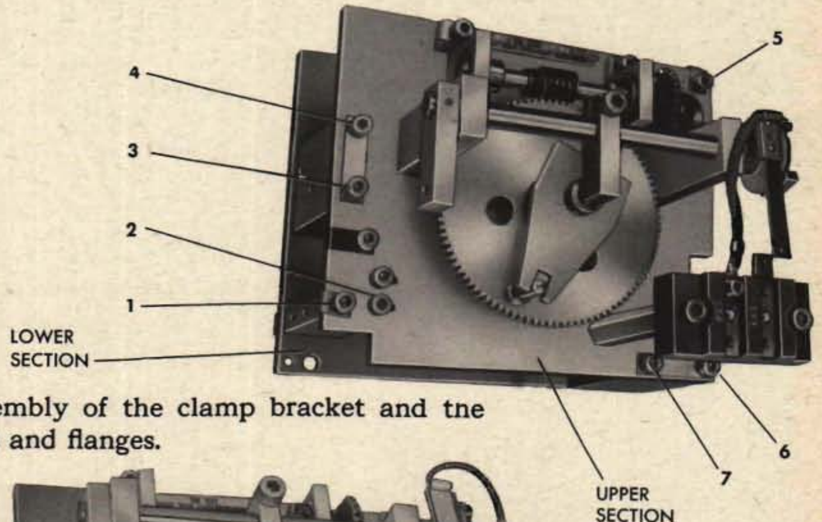


8 From the top, insert any pins which have been removed. Push them in part way. Hold a small screw driver between the coils and push the pin in the rest of the way. *Do not use force* or the spring will be damaged.

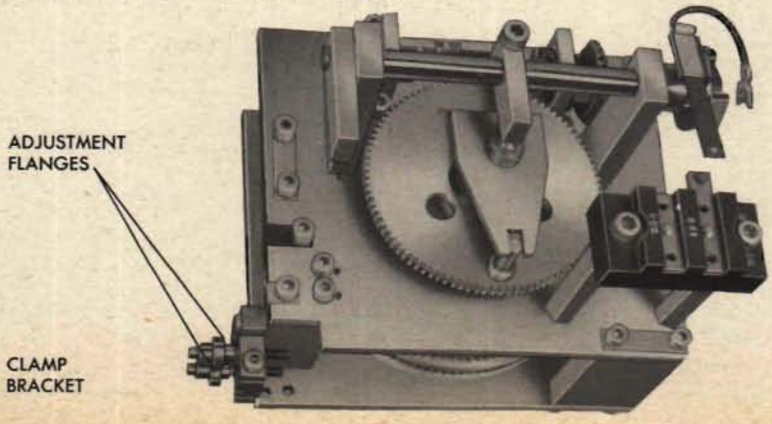
To even out the pins, turn the time disk counterclockwise.

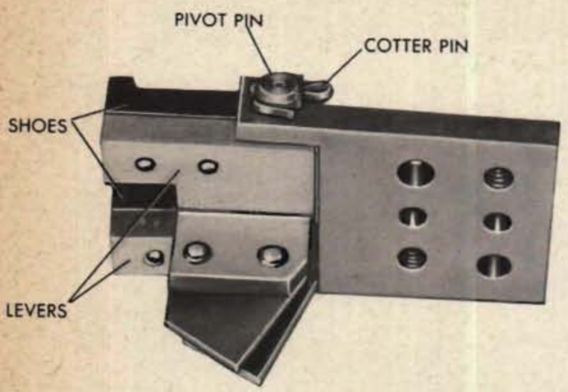


9 Put the upper and lower sections together and replace the seven screws.

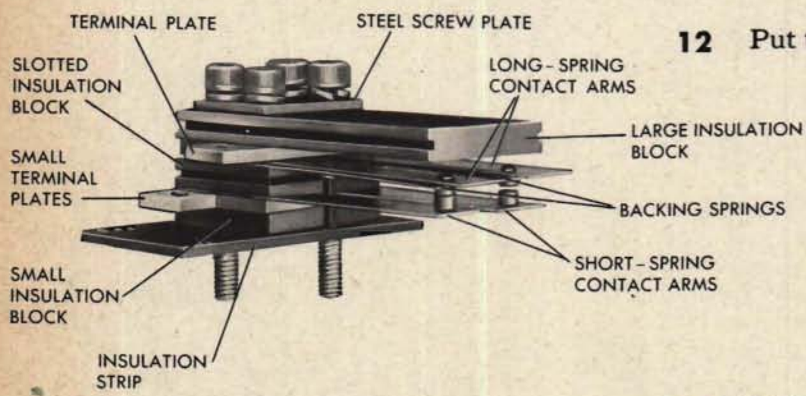


10 Remount the assembly of the clamp bracket and tne adjustment screws and flanges.



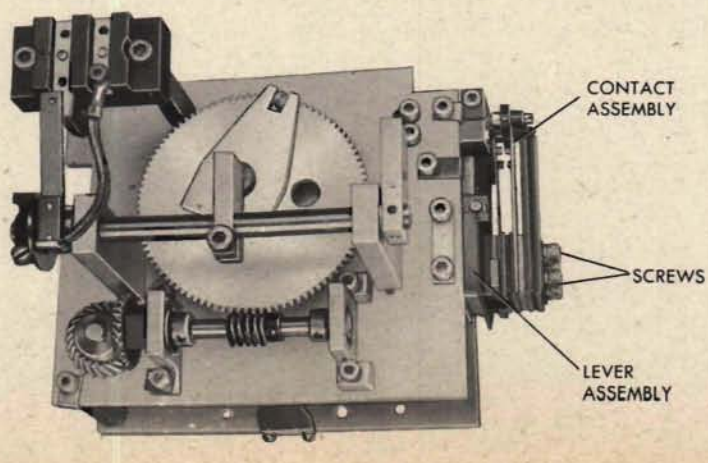


11 Reassemble the levers and the shoes on the pivot pin and fasten with the cotter pin. *Do not omit the tagged spacer.*



12 Put the contact assembly together.

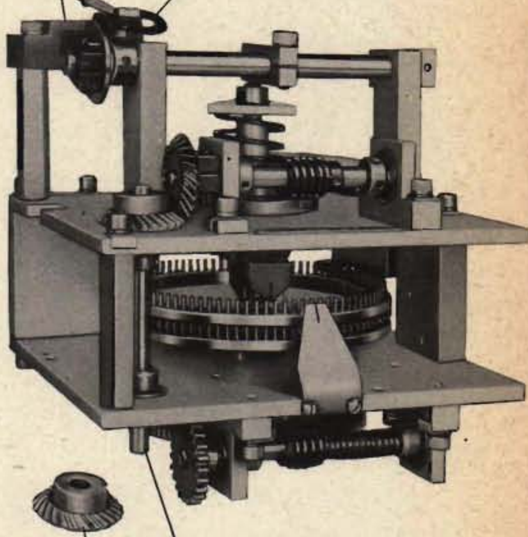
13 Remount the contact assembly and lever assembly on the unit.



14 Pin the bevel gear to the shaft.

15 Connect the pigtail to the terminal block.

16 Adjust the contact assembly mechanically and tighten the screw on the clamp bracket.



Bench checking the signal mechanism

1 All gears, bearings, and other moving parts should be lubricated with approved lubricant.

2 All contacts should be clean.

3 All moving parts, such as the setting arm, the linkage, the crank arm, and pins in the time disk, should operate freely.

4 There should be minimum lost motion between the gears, and minimum end shake in the shafts. The lines should turn freely.

5 The movable worm on the time input shaft should be free to move axially on the input shaft.

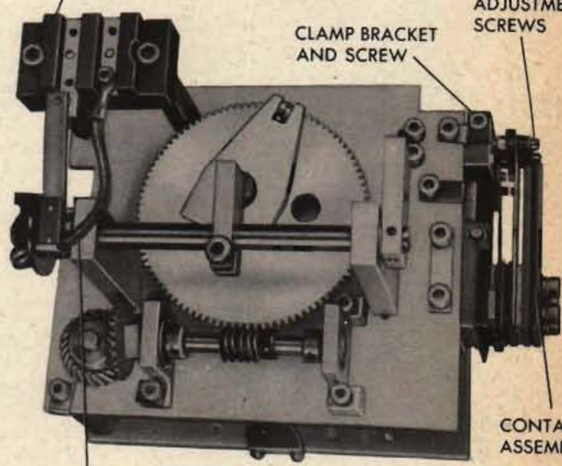
6 All adjustment clamps, including the clamp bracket and screw, should have sufficient holding power.

7 The pins should strike the levers correctly.

8 The levers should move freely on the pivot pin.

9 The contact assembly should be checked with the assembly drawing.

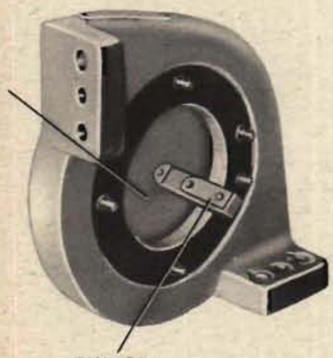
10 When the time disk is turned so that a pin engages both levers, the contact adjustment screws should be positioned so that the contacts make light but definite contact.



THE SOLENOID BUZZER
FRONT VIEW

THE SOLENOID BUZZER
REAR VIEW

DIAPHRAGM



PLUNGER

SOLENOID BUZZER

Typical symptoms

The best way to test for trouble is to pass 115-volt A.C. through the coil. If the buzzer does not give a steady signal, look for the following:

No sound

Intermittent sound

Tinny sound

Weak sound

Locating the cause

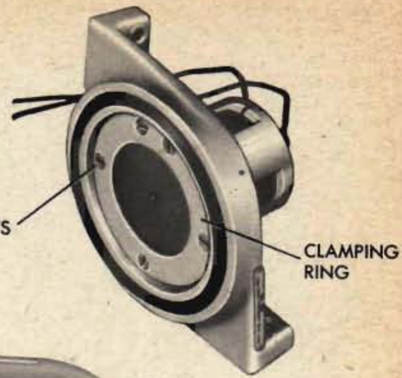
LACK OF SOUND may be due to the following causes: The plunger in the coil assembly may be jammed so that the diaphragm cannot vibrate. The adjusting stop screw may be moved so far in that the plunger cannot function. The coil in the buzzer may be shorted or burned out. The soldered lead may be broken off at the coil terminal.

AN INTERMITTENT SOUND will result if the plunger is sticky.

A TINNY SOUND may be caused by a cracked diaphragm.

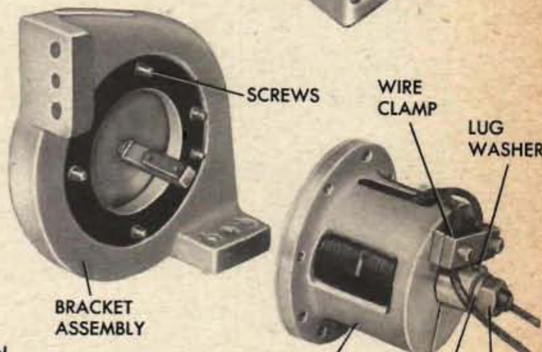
A WEAK SOUND or a hum indicates that the stop screw has backed out so far that the plunger cannot strike.

Disassembling the buzzer

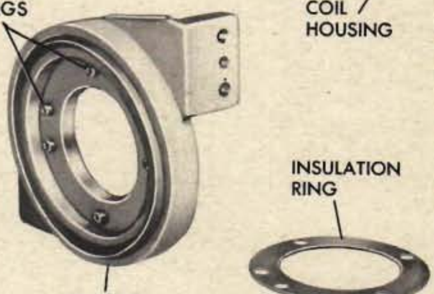


1 Loosen the five long flat-head screws which are staked in the clamping ring. This will separate the coil assembly and the bracket.

2 Remove the bracket assembly parts in this order: screws, clamping ring, insulation ring, diaphragm and plunger, insulation ring, bracket, and the other insulation ring.



NOTE: There are five bakelite bushings in the bracket through which the flat-head screws pass.



3 From the rear of the coil housing, remove the two bakelite pieces which act together as a clamp for the leads.

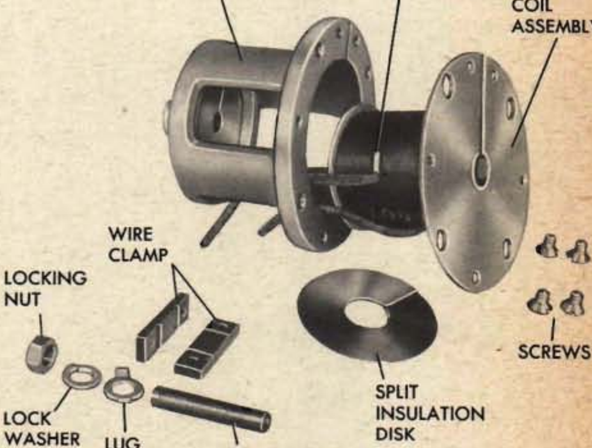
4 Remove the hexagonal locking nut, lock washer, and lug washer.

5 Back the adjusting screw out of the coil housing.

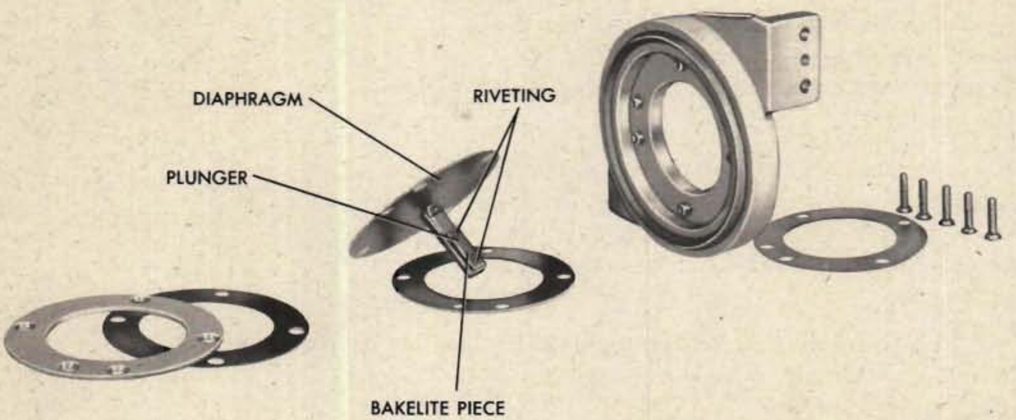
6 From the other end of the coil housing, remove the four small flat-head screws which hold the coil in the housing. Be careful not to break the connection at the coil terminal.

7 Separate the coil assembly from the housing.

8 The split insulation disk between the coil assembly and the housing can be removed by pushing or lifting it out. Be careful not to break it.

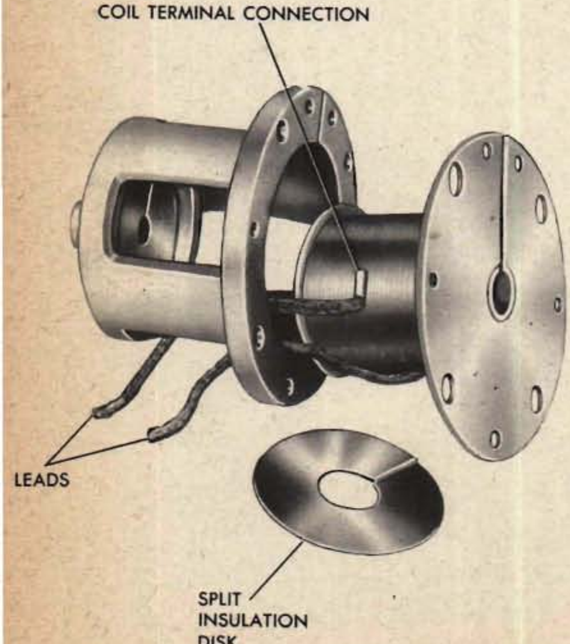


Repairing the parts



Repairing a jammed or stuck plunger

Remove the diaphragm and the plunger which is riveted to it. Then remove the high spots from the bakelite pieces on the plunger. *Do not use lubricant to relieve binding.*



Replacing a burned-out or shorted coil

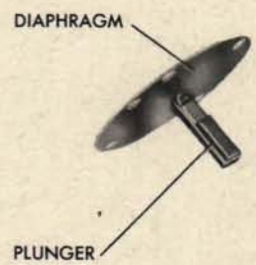
A burned-out or shorted coil must be replaced. In an emergency where no replacement is available, the coil assembly can be rebuilt. Consult the assembly drawing for wire size and construction details.

Repairing broken leads or terminal connections

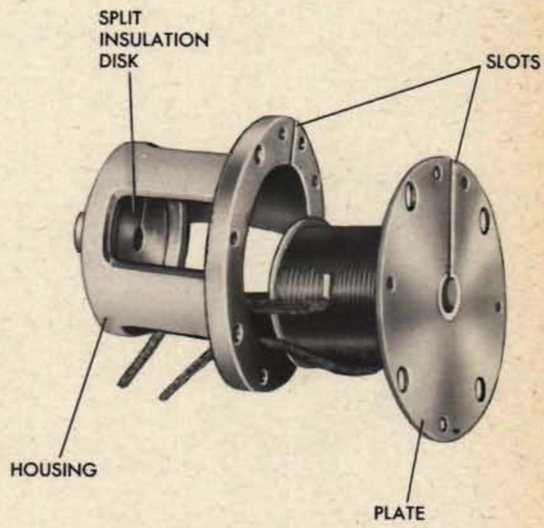
See the chapter on *Wiring*, page 380.

Replacing a cracked diaphragm

If the diaphragm is cracked, both the diaphragm and the plunger must be replaced. When riveting, make sure that the plunger is perpendicular to the diaphragm.



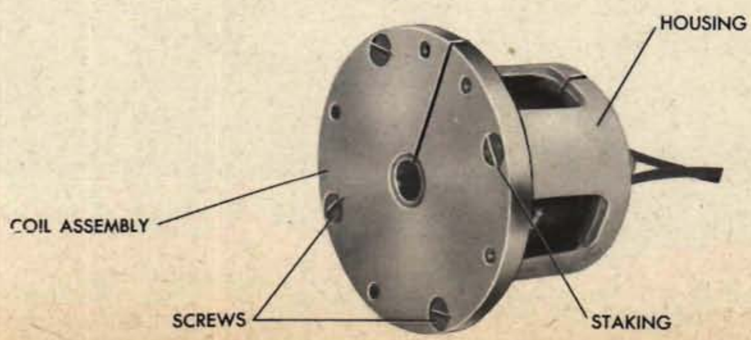
Reassembling the buzzer

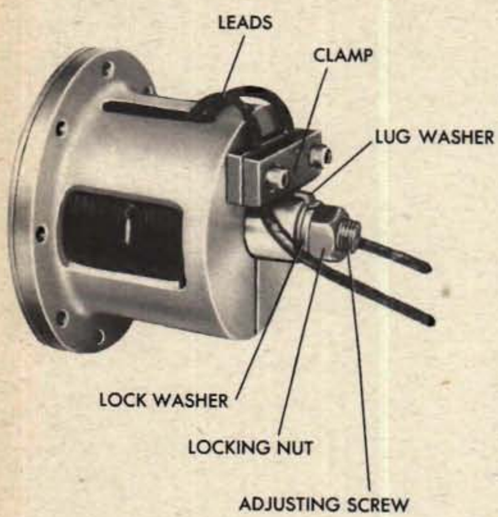


1 Replace the split insulation disk in the housing.

2 Run the leads from the coil assembly through the opening in the housing. Line up the slot in the coil assembly plate with the slot in the housing.

3 Seat the coil assembly in the housing and secure it with the four screws. *Stake the screws.*

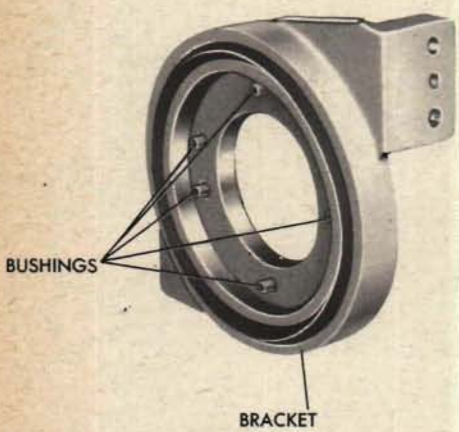




4 Replace the adjusting screw with its slotted end out.

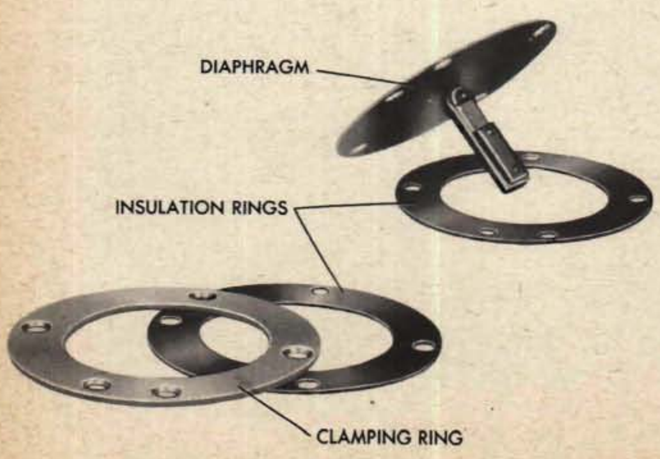
5 Remount the lug washer, lock washer, and the locking nut on the screw.

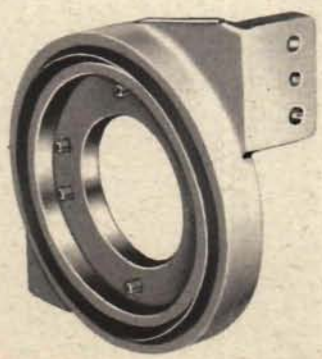
6 Fasten the leads to the housing by means of the bakelite clamp. To avoid breaking the connections at the coil terminal, be sure the leads are left slack.



7 Replace the five plastic bushings in the bracket.

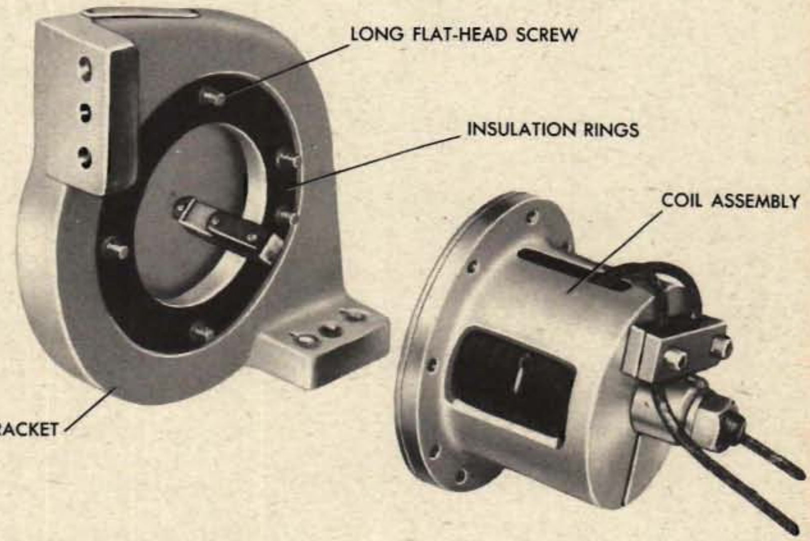
8 Mount the rings and the diaphragm in their correct order in the bracket, *with the insulation rings between the metal parts.*





9 Insert the five long flat-head screws. Put the insulation ring over the ends of the screws. Mount the coil assembly and tighten the screws.
Be very careful not to break the diaphragm at the point where it is riveted to the plunger.

10 Apply 115-volt A.C. to the coil. Turn the adjusting screw to obtain the maximum volume of sound. Tighten the locking nut.



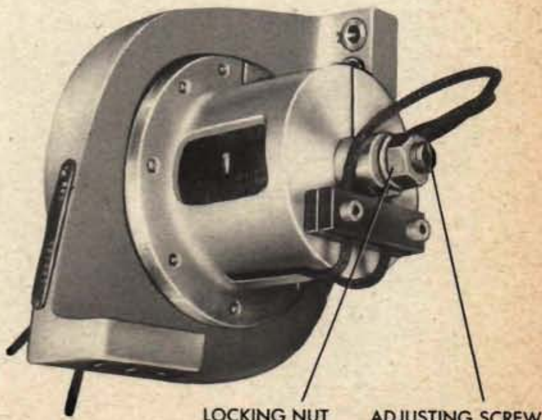
Bench checking the buzzer

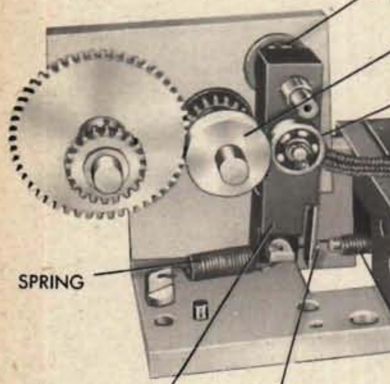
1 The leads should be soldered to the coil.

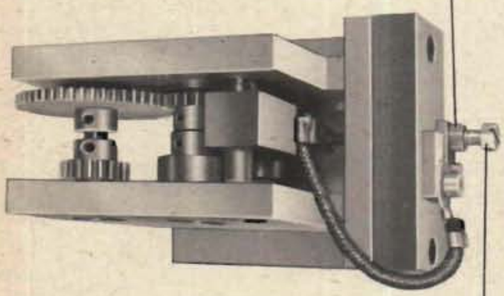
2 All the flat-head screws should be staked.

3 Test the volume of sound by passing 115-volt A.C. through the unit.

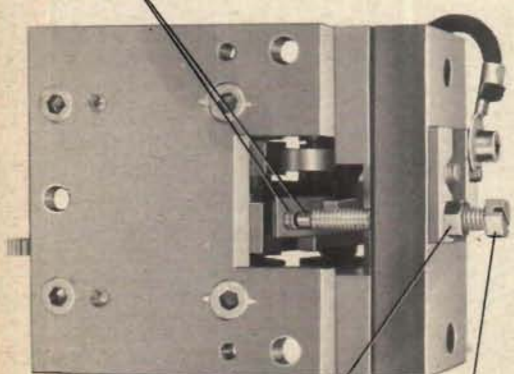
4 The locking nut should be tight.







TOP VIEW



BOTTOM VIEW

CURRENT INTERRUPTER

Essentially, the current interrupter is a pair of contacts which are made to open and close rapidly. One contact is attached to a pivoted bakelite arm; the other contact is mounted in a screw. A follower on the arm is held against a cam by spring tension. Turning the cam opens and closes the contacts.

Typical symptoms

If the buzzers do not sound the time of flight interrupted signal properly, the current interrupter may be at fault. Look for one of the following typical symptoms in the current interrupter.

JAMMING: The shaft line cannot be turned, or the bakelite arm cannot pivot.

STICKING: The shaft line resists turning past certain points or turns sluggishly. The bakelite arm pivots sluggishly.

ELECTRICAL TROUBLE: The buzzer circuit does not open and close, even though the contacts do.

Locating the cause

Jamming or sticking

A jammed or sticky shaft line may be the result of dirty or damaged gear teeth or bearings. If the gearing is jammed the buzzer circuit may be open or may be closed continuously, depending on the position of the cam.

A jammed or sticky bakelite arm is usually due to dirty or damaged bearings. If the bakelite arm does not pivot, the buzzer circuit usually is closed.

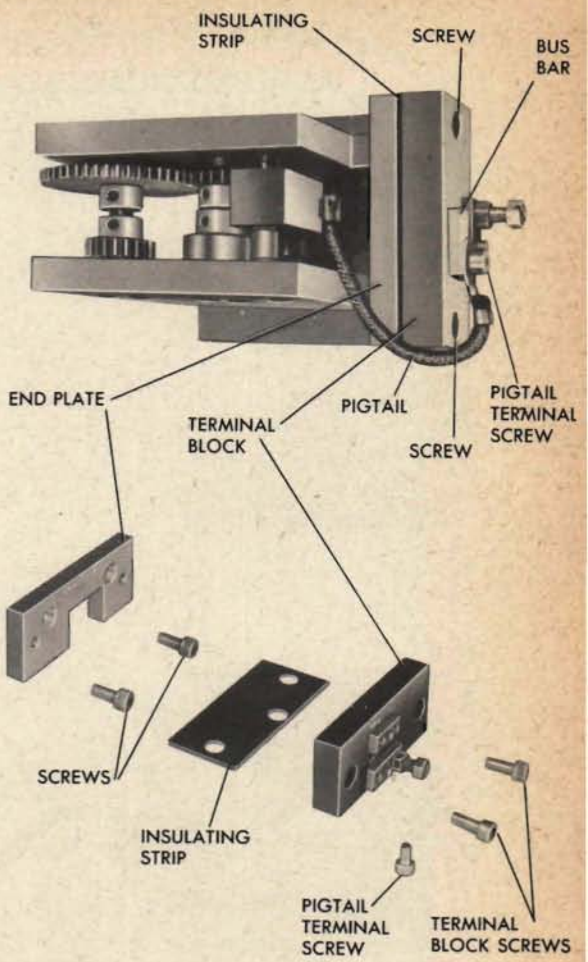
Electrical trouble

If the buzzer circuit is open, even though the contacts can be seen to close as the cam rotates, probably the pigtail lead has an open or the contacts are dirty.

If the buzzer circuit is not functioning properly, even though all parts seem to operate smoothly, probably the contact screw is out of adjustment. If the circuit is always closed, the contact may be screwed in too far. If the contact is always open, the contact screw may be backed out too far. The contacts can be adjusted without removing the current interrupter from the instrument. Always tighten the locking nut after an adjustment has been made.

Disassembling the current interrupter

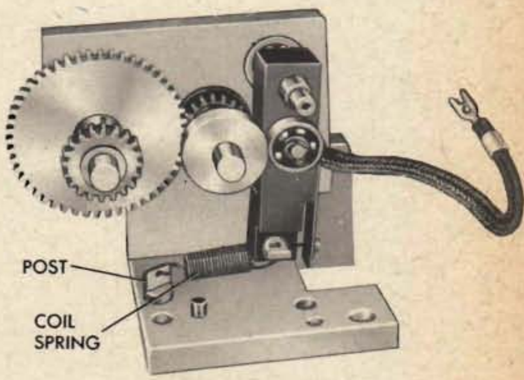
Disconnect the leads from the bus bars of the current interrupter. Take out the two screws which fasten the unit to the large plate and remove the unit from the instrument.



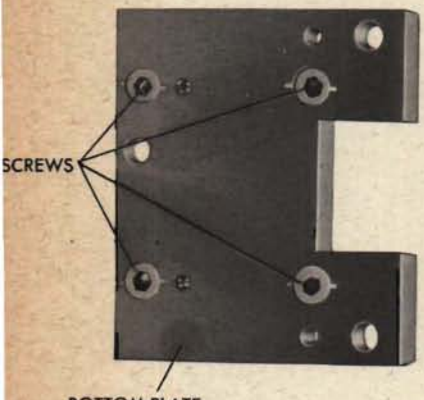
1 Disconnect the pigtail wire from the bus bar.

2 Remove the two screws holding the terminal block and insulating strip to the end plate.

3 Take out the two screws holding the end plate and lift off the plate.

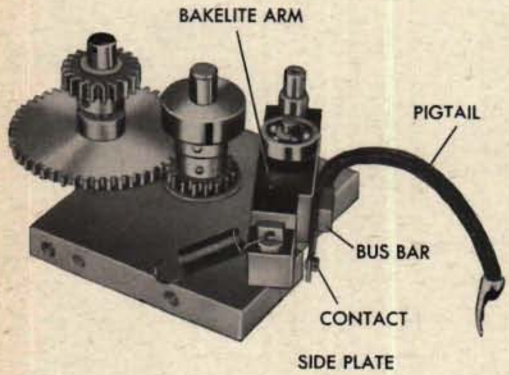


4 Unhook the coil spring from the post in the bottom plate.



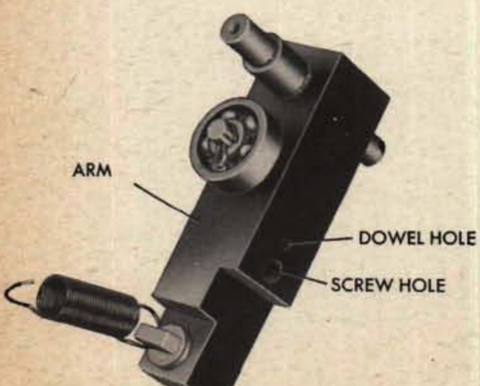
5 Remove the bottom plate by taking out the four staked screws.

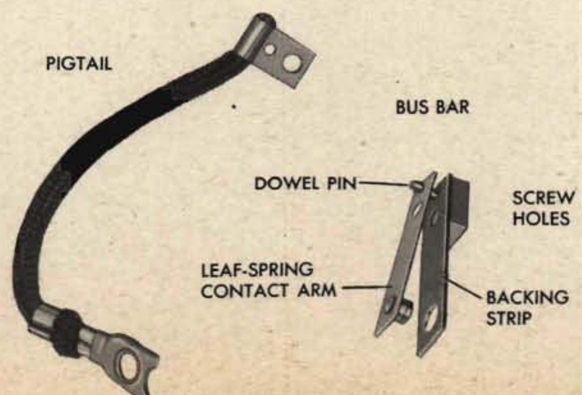
6 Separate the two side plates and remove the small shafts. Tag the spacers on the shafts.



7 Remove the screw from the bus bar on the bakelite arm.

8 Separate the pigtail, backing strip and leaf-spring contact arm which are secured to the bakelite arm by a dowel pin and a screw.

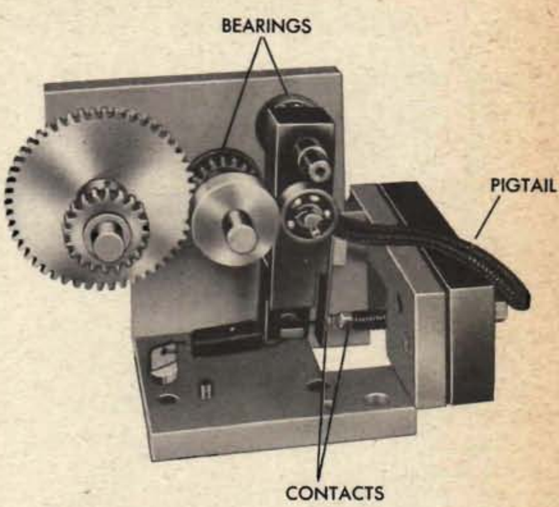




Repairing the parts

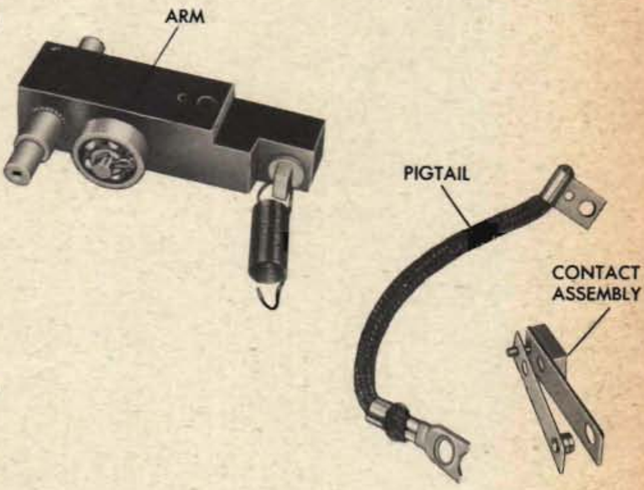
Cleaning the parts

Dirt should be removed by cleaning the parts with an approved solvent. Clean and repair the contacts, as described on page 521.



Repairing gear teeth, bearings, pigtails

Many repairs can be made without disassembling the unit. Burrs on gear teeth may be removed by a fine jeweler's file. Damaged bearings or damaged contacts should be replaced. If it is necessary to replace a pigtail, refer to the chapter on *Wiring,* page 380.

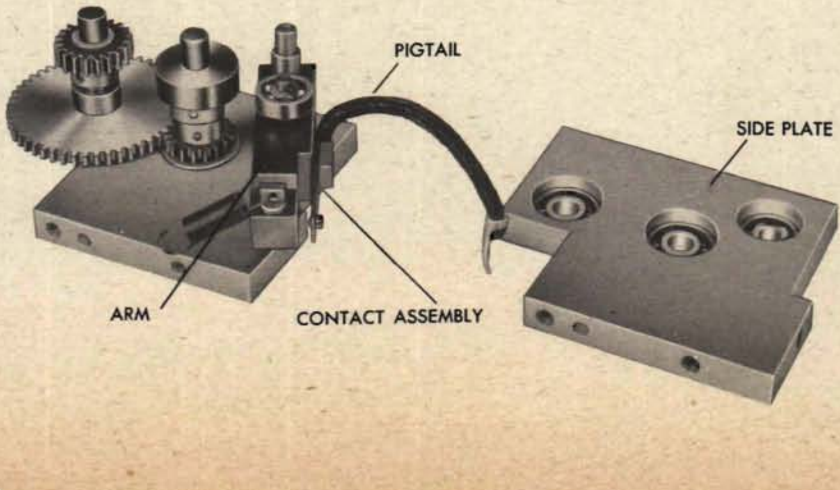


Reassembling the current interrupter

1 Remount the contact assembly and the pigtail on the bakelite arm.

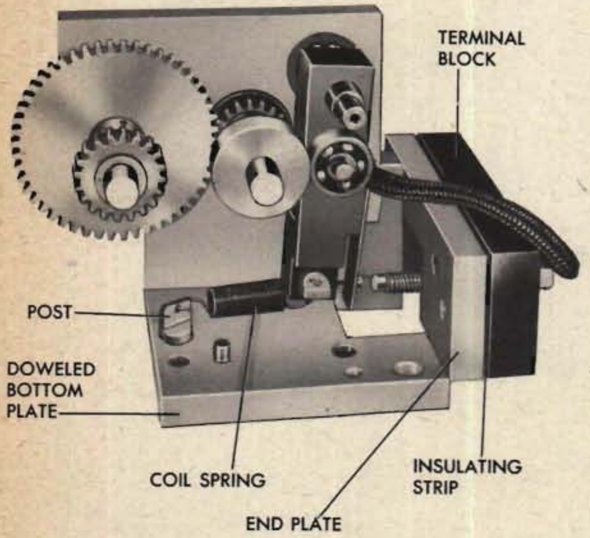
2 Replace the three shafts in the plate, using the correct spacers.

3 Set the shafts in the other side plate.



4 Mount the assembly on the bottom plate and stake the four screws.

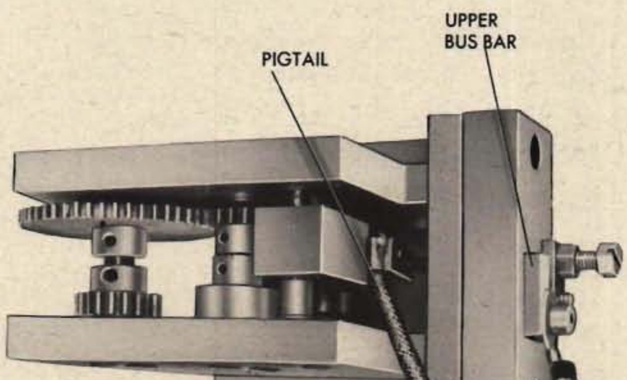
Attach the coil spring to the post on the plate.



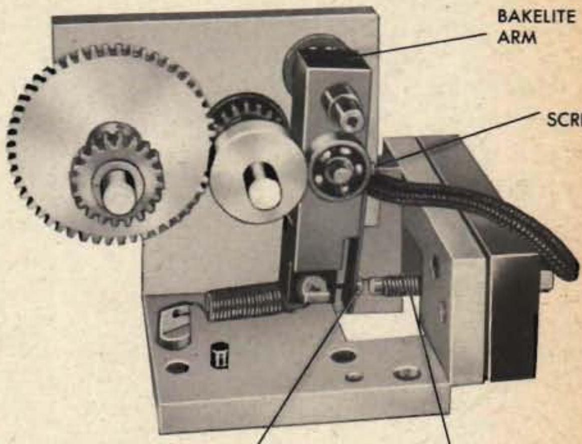
5 Replace the end plate.

6 Replace the insulating strip and the terminal block.

7 Connect the pigtail to the upper bus bar.

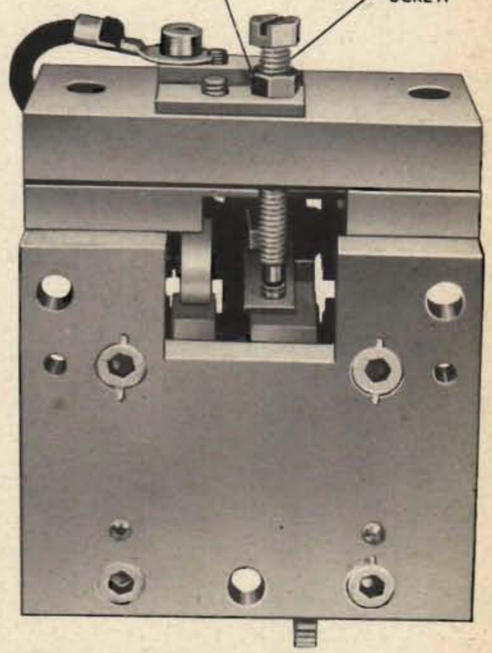


8 Make sure that the contacts are aligned. The screw in the bakelite arm can be used to align the contact assembly with the adjustable contact.



9 Adjust the contact gap and tighten the locking nut.

Bench checking the contact interrupter



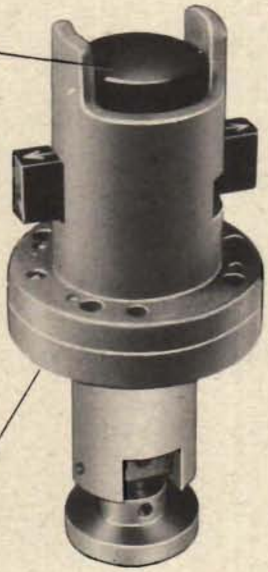
1 The bearings and gears should be lubricated with an approved lubricant.

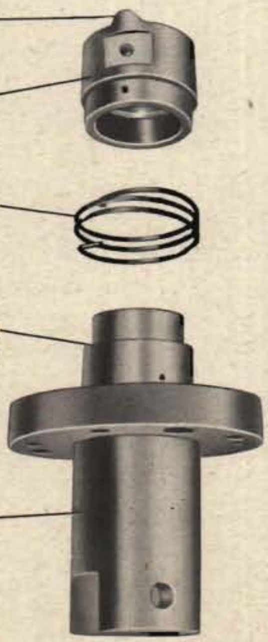
2 The gears should turn freely.

3 The contacts should touch each other squarely.

4 The contact screw should be locked.

5 The spring should be hooked to both posts.





SIGNAL BUTTON

Typical symptoms

One or more of the following typical symptoms will indicate the source of trouble when the signal button does not operate properly.

JAMMING: The button cannot be moved.

STICKING: The button resists moving past certain points, or it operates sluggishly.

FAILURE TO RETURN: The button or sleeve, even though free to move, does not spring back to normal position.

Locating the cause

Jamming or sticking may be caused by dirt in the adapter or between moving parts.

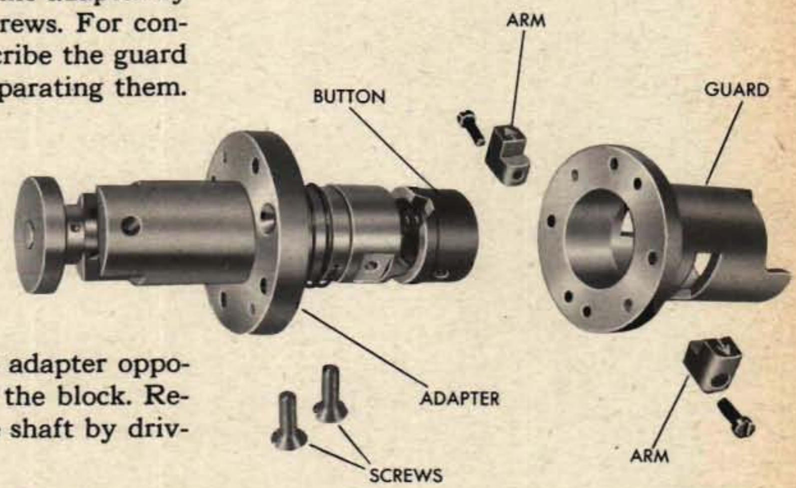
A burred or bent shaft may cause sluggish movement or binding of the button. Binding of the sleeve may occur if the torsion spring wrapped around the sleeve gets caught between the sleeve and the adapter shoulder.

If the sleeve feels sluggish when being turned, it may be seizing on the adapter due to inadequate lubrication. If the sleeve fails to spring back after being turned, the torsion spring may be unhooked.

Disassembling the signal button

1 Remove the two arms which form the sleeve.

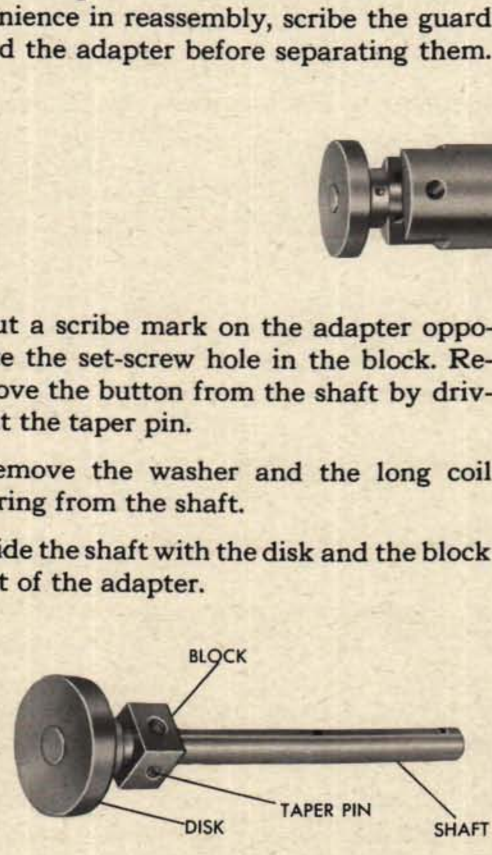
2 Separate the guard from the adapter by removing the flat-head screws. For convenience in reassembly, scribe the guard and the adapter before separating them.

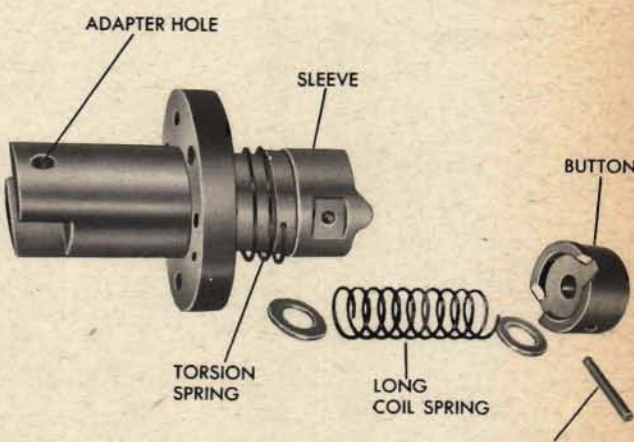


3 Put a scribe mark on the adapter opposite the set-screw hole in the block. Remove the button from the shaft by driving out the taper pin.

4 Remove the washer and the long coil spring from the shaft.

5 Slide the shaft with the disk and the block out of the adapter.



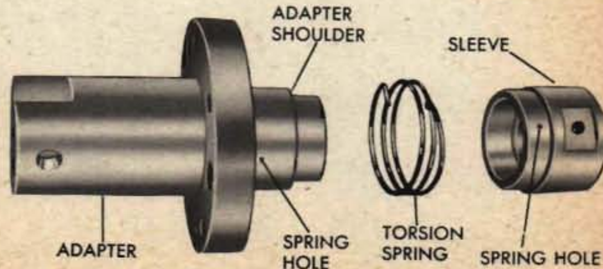


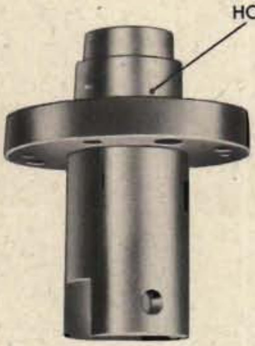
6 Drive out the taper pins to remove the disk and block.

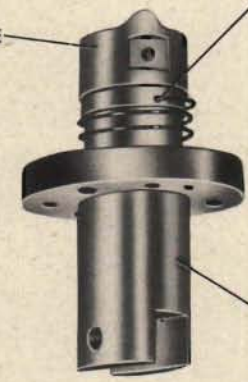
7 Remove the sleeve by unhooking the torsion spring from the hole in the sleeve.

8 Take the other washer out of the adapter.

9 Remove the torsion spring from the adapter by taking the long hook out of the hole.







Repairing the parts

Disassembly is usually required, since most of the trouble in the signal button results from binding.

Cleaning and repairing the parts

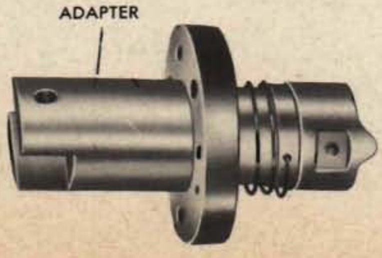
The parts should be cleaned with an approved solvent to remove any dirt and to permit the detection of burrs. Burrs should be removed, and the parts then polished. A new spring can be made if the torsion spring is damaged and the sleeve is not returning properly.

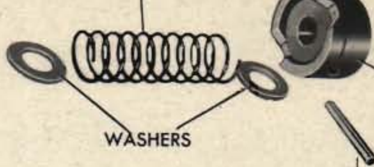
Lubrication

All parts should be lubricated with an approved lubricant before reassembly.

Reassembling the signal button

1. Replace the torsion spring, putting the long hook in the hole in the adapter.
2. Push the spring down and remount the sleeve. *Lubricate the inside and outside of the sleeve and the adapter.*
3. Put the short hook in the hole in the sleeve. The sleeve should seat on the adapter shoulder and *not* on the spring coil.
4. Repin the block and disk to the shaft and stake the pins. Lubricate the shaft and mount it in the adapter, using the mark made during disassembly as a guide.





5 Put the washer on the shaft.

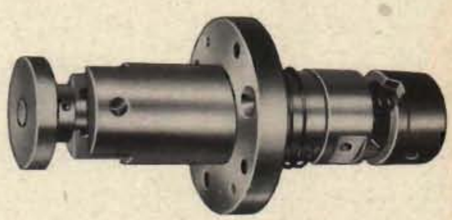
6 Put the long coil spring on top of the washer.

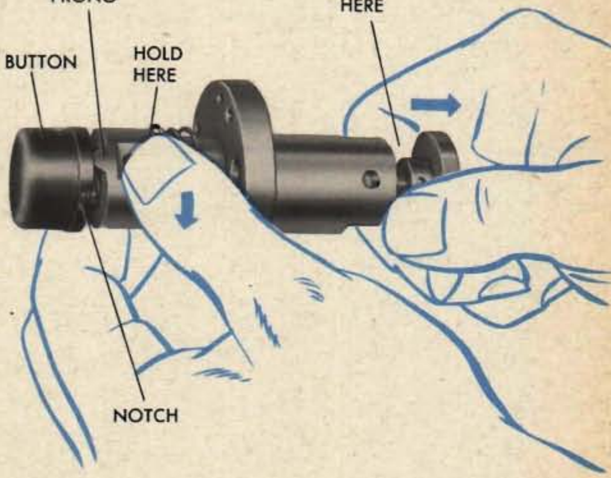
7 Replace the other washer and the button. Drive in the taper pin and stake it.

8 Replace the guard and one arm as follows: Hold the adapter and pull the disk down. Wedge the fingers between the adapter and the disk. Revolve the sleeve and pull down the disk until the prong of the sleeve is seated in the notch of the button. *Be sure that the torsion spring is in the correct position.* Holding the parts in this position, *replace the guard,* and remount one of the arms.

9 Remount the other arm.

10 Secure the adapter and guard with the two flat-head screws, and stake the screws.



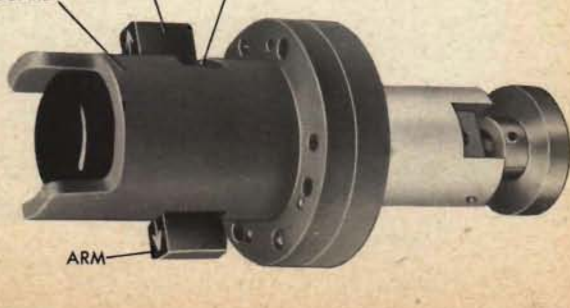


Bench checking the signal button

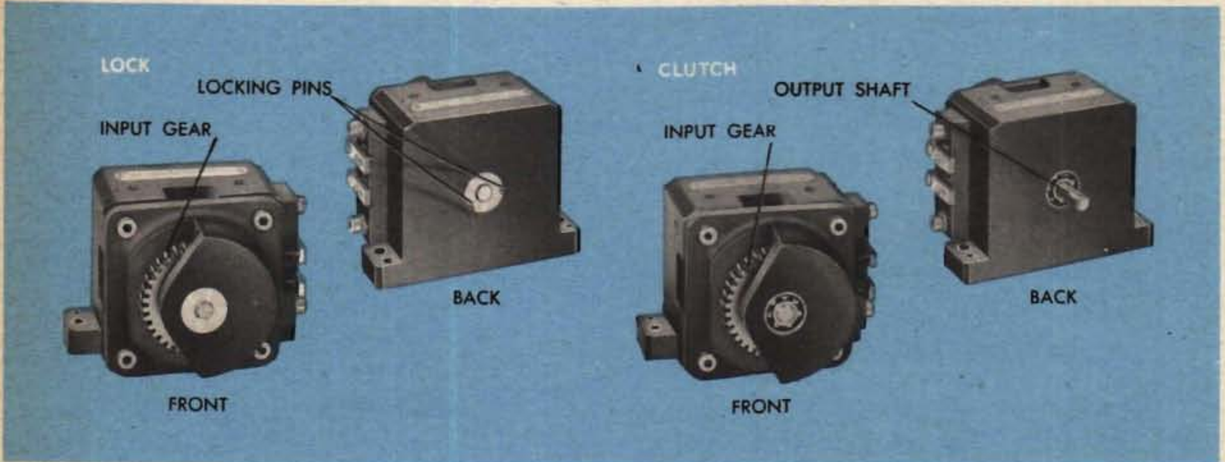
1 The arms should turn easily through their full travel to the point where they strike against the limits of the cutout section in the guard. Then, when released, the arms should spring back to the opposite limits of the cutout section.

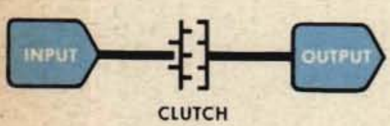
2 It should be possible to push the button down ⅛ inch with the arms in the normal (time of flight) position and ¼ inch when they are turned clockwise (spotted salvo position).

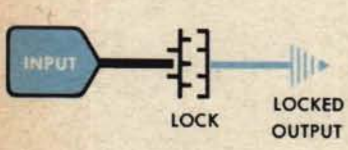
3 The button and the arms should spring back to the normal position when released.



THE SOLENOID LOCK AND CLUTCH







A solenoid lock is used to prevent a shaft line from turning. *A solenoid clutch* connects and disconnects a shaft line.

The chief difference between them is that one jaw of the lock is fixed to the unit housing, while both jaws of the clutch are free to turn. Since the two units may develop similar troubles, they are discussed together.

When the clutch is engaged, the clutch output line is connected to the input line. When it is open, or not engaged, the output line is not connected to the input line and is not driven, even though the input line continues to turn.

When the lock is energized, its jaws engage and the shaft line is prevented from turning.

Checking operation within the instrument

It is assumed in this check within the instrument that the shaft lines are free.

With the power ON and the input shaft turning, energize the unit. When energized, a lock must prevent a line from turning. A clutch should drive an output line when the clutch input line is turned.

Turn the power OFF. The lock or clutch should then disengage.

Slipping may be checked when the unit is energized. If it is slipping, the unit may sound like a ratchet device. If the locking pins are sheared, a lock may make a scraping sound.

A unit may sound noisy for other reasons, but still function normally. Noise usually indicates that trouble is developing, however. If the cause is not eliminated, the unit may develop trouble within a short time.

Typical symptoms

Sometimes failure of a unit may be traced to faulty wiring, a faulty push-button switch, or a lack of power to energize the unit.

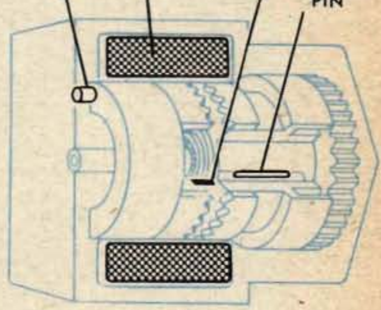
If the input shaft line, the switch, and the input wiring are normal, a solenoid lock or clutch may behave abnormally in one of four ways:

The unit may fail to engage.
The unit may engage, but slip.
The unit may engage, but fail to release.
The unit may be noisy.

Locating the cause

Failure to engage

If the unit fails to engage, the trouble may be due to one or more of these causes:



LOCK

Open or defective solenoid coil. Replace the solenoid coil or replace the unit.
Rusted or dirty pins in the sliding half of the lock or clutch, or dirt in the pin track. The pins should be cleaned. Earlier models of locks and clutches use steel balls instead of pins. In units of this type, replace the balls with pins.
Improperly adjusted pronged spring. Disassemble the unit and adjust the spring. This spring has two functions. It aids the small coil springs in separating the jaws of the clutch, and at the same time it acts as a shading coil to reduce the noise caused by the 60-cycle pulsation.
In a lock, the locking pins may have sheared off or fallen out. Disassemble the unit and replace the locking pins.

Slipping

A lock or clutch may engage but slip if it has one of the following troubles:

Rusted pins. Clean or replace the pins.
Dirt in the pin track. Clean the pins and track.
Improperly adjusted pronged spring. Disassemble the unit to adjust the spring.
Overloaded or jammed output line. Refer to the instrument OP.

Failure to release

A lock or clutch which does not release may have one or more of these troubles, all of which require disassembly:

Rusted pins. Clean or replace the pins.
Dirt in the pin track. Clean the pins and the track.
Weak or rusted coil springs. Replace the springs.
Improperly adjusted pronged spring. Adjust the spring.

Noisy unit

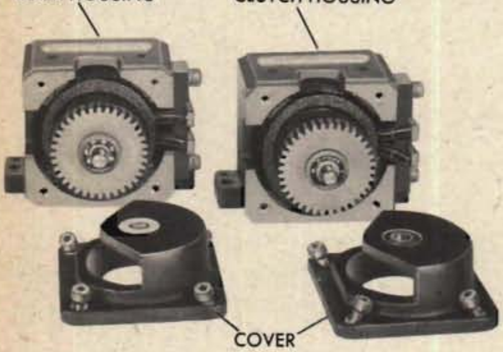
If the unit is noisy, check for these troubles:

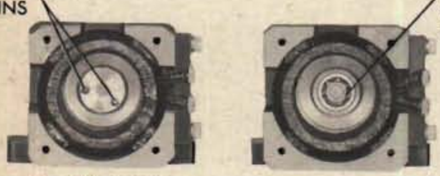
Improperly adjusted pronged spring. Disassemble the unit and adjust the spring.

Poor alignment of parts. Disassemble the unit and realign the parts.

Sticking clutch teeth. Disassemble the unit and clean the teeth.

Overloading. If the output shaft line is overloaded, the teeth of one jaw may slip on those of the other and force the shifting mechanism back along the shaft. Consult the instrument OP.





CLUTCH MECHANISM

Disassembling and repairing the units

1 Remove the cover from the housing.

2 Lift out the clutch mechanism and the shaft. The clutch mechanism consists of the lower hub and jaw, the spacer and the pronged spring, and the shifting mechanism. All these parts are free on the shaft except the lower hub and jaw which are pinned to the shaft.

3 To check the shifting mechanism, pull it apart slightly and allow it to snap back together. This action must be free. If the mechanism sticks, it requires cleaning or polishing.

4 Check further by holding the clutch jaw in one hand and pulling out the gear and turning it. While turning it, press the gear back against the jaw. The gear should slide into place easily without sticking. If the movement is sticky, the pins may be dirty, rusted or worn. Test for excessive lost motion by turning the gear back and forth in the hub. New pins must be used if the lost motion is excessive.

5 To disassemble the shifting mechanism, hold it with the clutch teeth facing downward. Use a thin rod inserted through the top bearing to tap the lower bearing out of place. Rest the rod on the outer race of the lower bearing and move it to a different point on the race after each tap. When removing this bearing, be sure not to damage it. Save the springs, pins, and retainer.

6 Before separating the gear from the hub, mark each part so that the pin holes can be matched during reassembly.

7 Pull the gear from the hub. If the two parts are stuck together, it may be necessary to drive them apart.

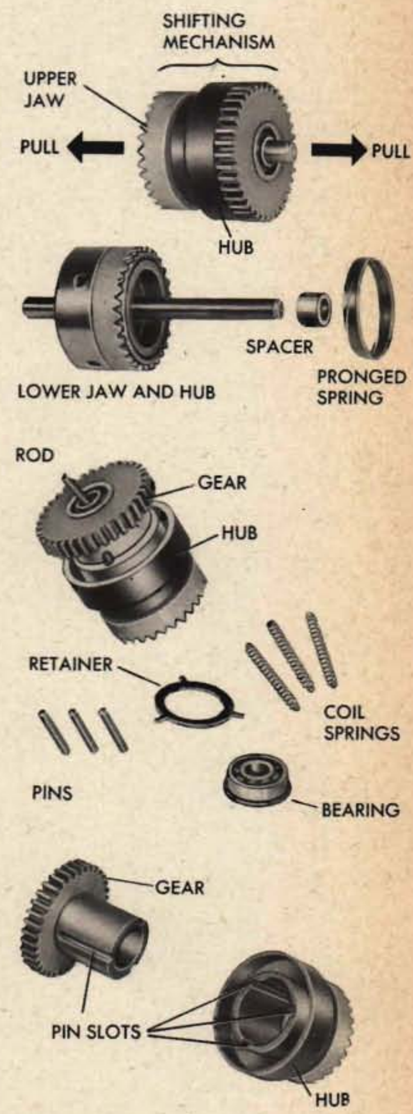
8 Wash out the pin slots. Run a pencil point along the slots to feel for roughness. Rough spots may be smoothed out by polishing. Use a piece of fine sandpaper wrapped once around a 0.100 inch rod.

9 Excessive lost motion may be caused by worn pins or slots. New pins should be made of a stainless-type steel or of phosphor bronze, 0.750 inch long and slightly over 0.125 inch in diameter. Polish the pins to size so that they fit smoothly. Wash the parts in solvent before inserting the pins.

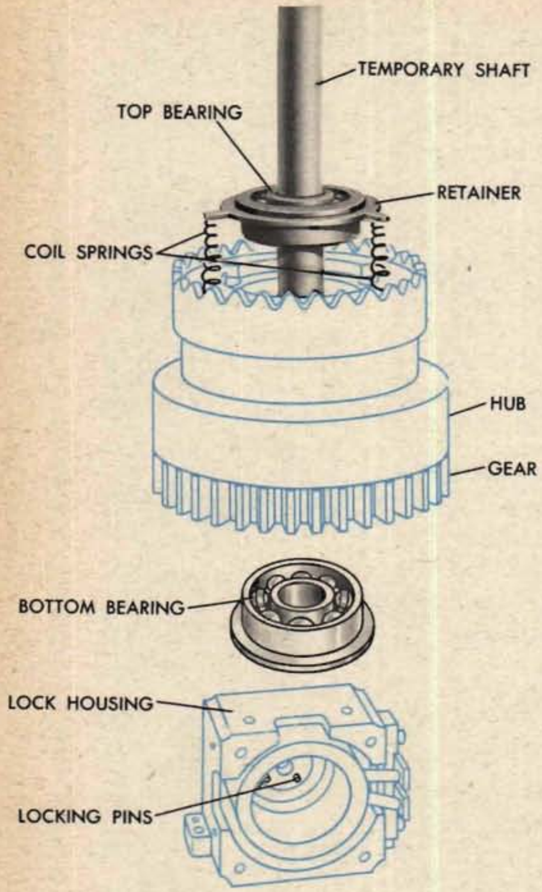
10 Refit the gear in the hub and insert the three pins.

11 Put a drop of oil on each pin.

12 Pull the hub about ¼ inch away from the gear. Holding the hub in one hand, turn the gear with the thumb of the other hand. While still holding this load on the gear, press the gear in toward the hub. It should slide in fairly easily if the surfaces are smooth and there is not too much lost motion between the gear, hub, and pins.



Reassembling the unit



When the gear slides into the hub freely, proceed with assembly. Make sure that all bearings are clean and free.

1 Replace the bottom bearing in the hub.

2 Insert a rod or temporary shaft through the hub and gear, and through the bottom bearing.

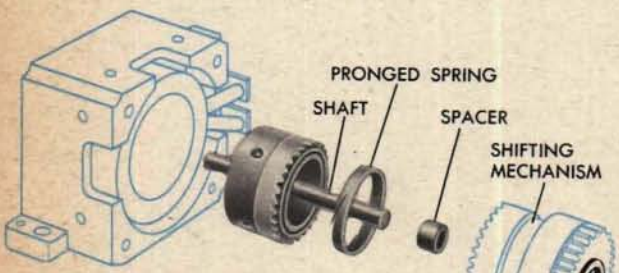
3 Insert the three coil springs.

4 Put the top bearing in the retainer.

5 Slide the bearing over the shaft, aligning the retainer fingers with the springs. Press the bearing down until it holds. If the retainer is permitted to turn, the springs will fly out.

6 Remove the temporary shaft.

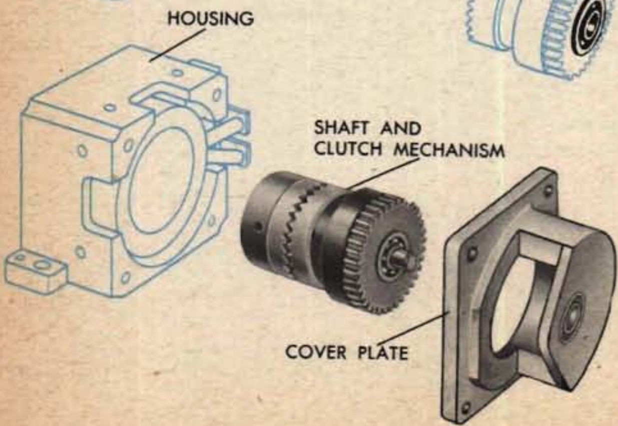
7 In a lock, check the locking pins in the housing to be sure they are not missing, bent, or sheared off.



8 Fit the pronged spring into the lower hub with the prongs down. The spring should be free in its groove.

9 Fit the spacer on the shaft.

10 Oil the bearings and the shifting mechanism.



11 Slide the shifting mechanism on the shaft.

12 Insert the shaft and clutch mechanism in the housing.

13 Replace the cover plate and fasten it with four screws.

Adjusting the unit

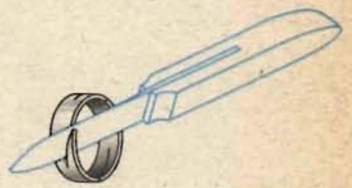
1 Energize and de-energize the solenoid several times. If the unit clicks when the power is turned OFF, the unit is engaging and disengaging properly.

2 If the unit does not disengage when the power is OFF, the prongs on the spring may not be bent out far enough.

3 If the unit chatters when the power is ON, the spring prongs may be bent out too far. To eliminate the chatter, remove the spring and carefully bend the prongs in about 0.005 inch.

4 If the unit sticks in its energized position, bend the prongs out equally.

5 When the unit engages and disengages properly, energize the coil again and turn the gear. If the unit hums, remove the spring and smooth the solid end of it with sandpaper on a flat plate. Again reinstall and recheck. Continue alternately sanding the back of the spring and bending the prongs until the hum is negligible.



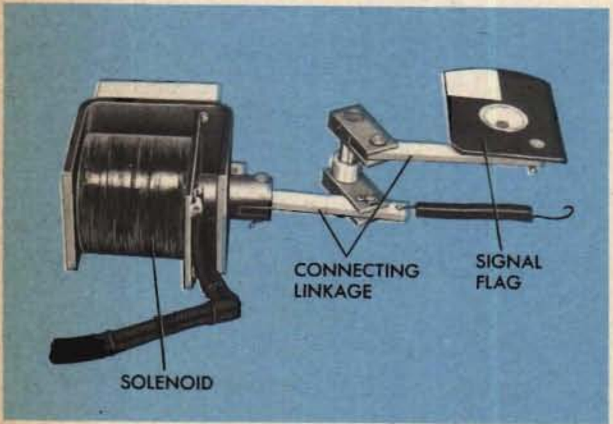
ADJUSTING SPRING PRONGS

Bench checking the unit

To simulate conditions of operation, turn the power ON and put a load on the unit by trying to turn the gear. In checking a clutch, fasten a bakelite clamp to the output shaft to prevent its turning. Keeping the load on, turn the power OFF. The mechanism should now release.

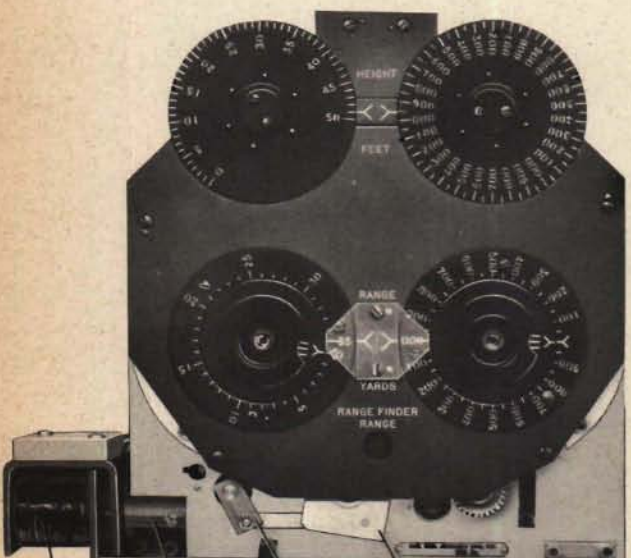
If it does not release, the spring prongs may not have been bent out far enough, or the shifting mechanism may not have been adjusted to eliminate sticking.

THE SOLENOID SIGNAL



The complete solenoid signal consists of a signal flag, a connecting linkage, and a solenoid which is controlled by a remote switch.

The parts of a solenoid signal are built into the gearing unit of the dial group to which it is related. The signal flag itself is visible through an opening in the dial mask. Since the solenoid signal cannot be removed from the instrument as a separate unit without disturbing other units, the trouble should be accurately located and an attempt made to effect repairs with the least possible amount of disassembly.



Typical symptoms

The solenoid signal may develop either electrical or mechanical trouble. If it is noted that the signal is not operating properly, look for the following typical symptoms.

JAMMING: When the solenoid is energized or de-energized, the plunger does not move.

STICKING: When the solenoid is energized or de-energized, the plunger resists the action of the solenoid or of the spring.

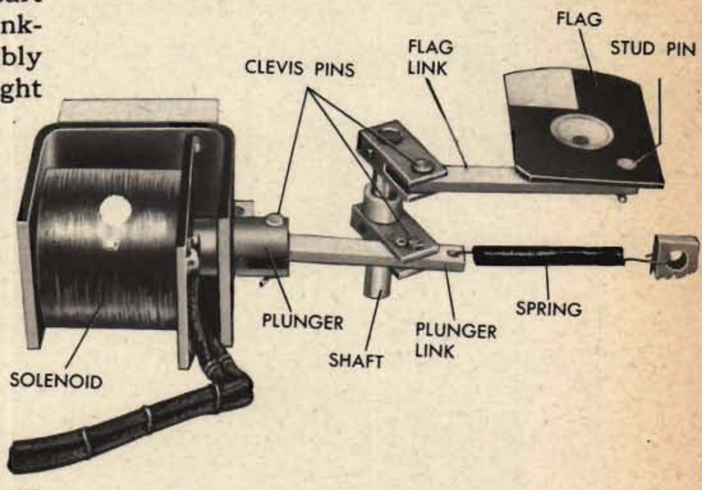
SLIPPING: Movement of the plunger does not move the signal flag, or the plunger will not move out of the solenoid when the solenoid is de-energized.

ELECTRICAL TROUBLE: The solenoid does not energize properly when the circuit is closed.

Locating the cause

Jamming or sticking

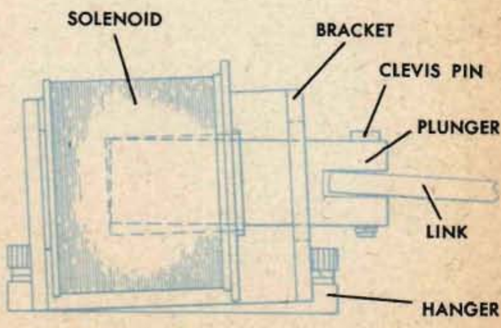
Jamming or sticking may cause complete failure of a solenoid signal or cause it to operate erratically or noisily. If the solenoid signal appears to be jamming or sticking, unhook the spring from the linkage and try to move the linkage back and forth by hand. If this does not reveal the source of trouble, disconnect the plunger from the linkage by removing the clevis pin which joins them. Swing the linkage aside and try each part separately. If both the plunger and the linkage are free after being separated, probably the solenoid is cocked or at the wrong height with respect to the linkage.



Besides a misaligned solenoid, the plunger may jam or stick because of dirt or oil inside the coil. Remove only the plunger to clean the inside of a coil, complete disassembly being unnecessary.

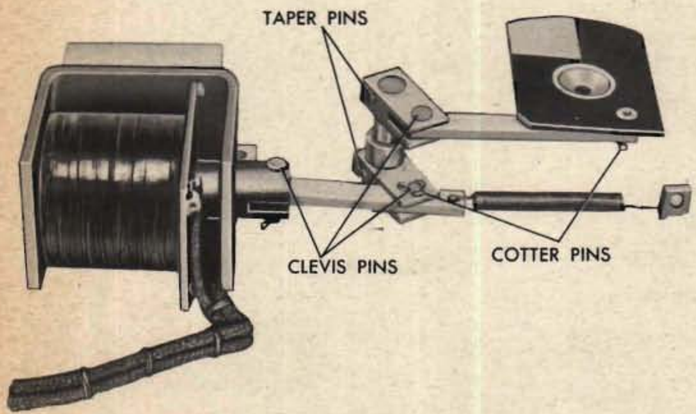
TRY PLUNGER ALONE

The linkage may jam or stick because of a frozen clevis pin, a dirty or damaged yoke, a bent link, a bent shaft, or a dirty or damaged bearing. A badly bent flag may also cause sticking or jamming by interfering with adjacent parts. Bearings can usually be cleaned, and yokes can be cleaned and polished in place, provided precautions are taken to protect the rest of the equipment. Bent links or shafts or parts which are otherwise damaged should be removed from the instrument for repair.



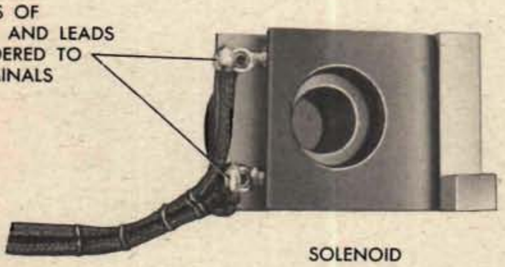
SOLENOID COCKED

The signal flag may fail to return to its normal de-energized position because of a weakened or unhooked spring. Before increasing the spring tension, be certain that the unit as a whole operates freely and that the spring *is* faulty, because excessive tension increases operating noise.



Slipping

If the signal does not move when the plunger is moved in and out of the solenoid, look for a missing taper pin or clevis pin. If a missing clevis pin is replaced, it should be fastened with a cotter pin.



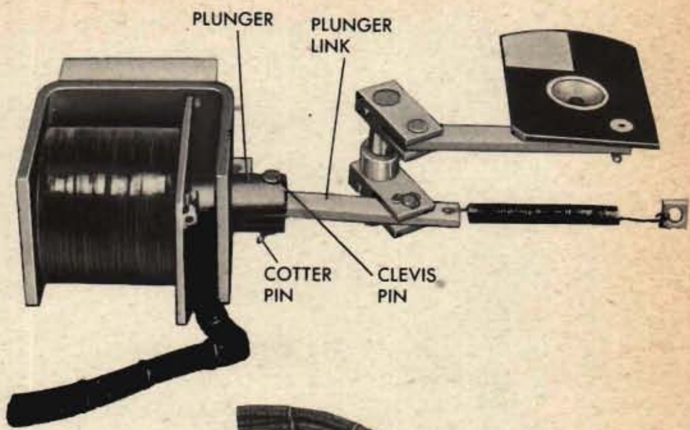
Electrical trouble

If the solenoid does not energize properly when the circuit is closed, look for a broken wire, a wire loose at the terminal, a broken coil wire at the terminal, an internal break in the coil, or a burned-out coil.

Examine the lead and coil connections at the terminal for breaks or looseness. A broken wire must be replaced and a loose wire repaired. Be sure that each of the two terminals is securely mounted. A loose or damaged terminal must also be repaired. Use an ohmmeter to check the coil for continuity. A coil with an internal break, or a burned-out coil, must be replaced. Follow the instructions given in the chapter on *Wiring*, page 384, in order to locate a break in the electrical circuit.

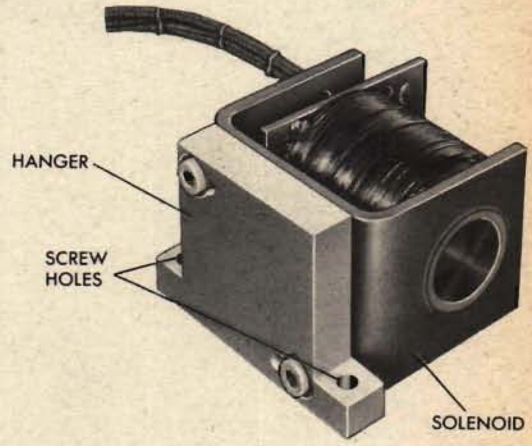
Disassembling the unit

As the solenoid signal is actually a part of another unit and disassembly of that unit upsets its adjustment to the instrument, the trouble should be isolated and if possible repaired in place. When a part must be removed for repair or replacement, if accessible it should be disassembled in the instrument. If the faulty part is inaccessible, the dial gearing unit will have to be removed and disassembled. The instrument OP should be consulted for instructions on removing the dial gearing unit.



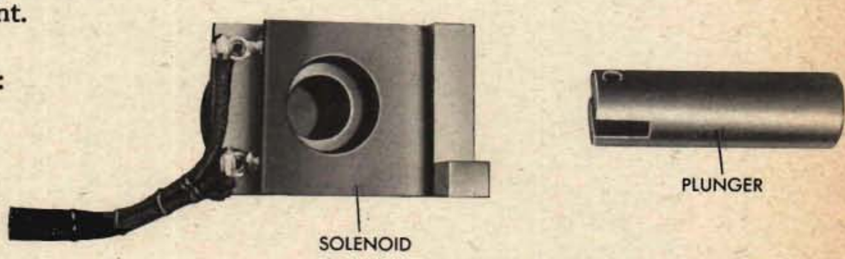
If only the solenoid must be disassembled, separate it from the other parts of the solenoid signal by removing the cotter pin and clevis pin which fasten the plunger to the plunger link.

Unfasten the two screws which hold the solenoid hanger to its mounting plate. Disconnect the leads from the terminal block and carefully lift the solenoid out of the instrument.

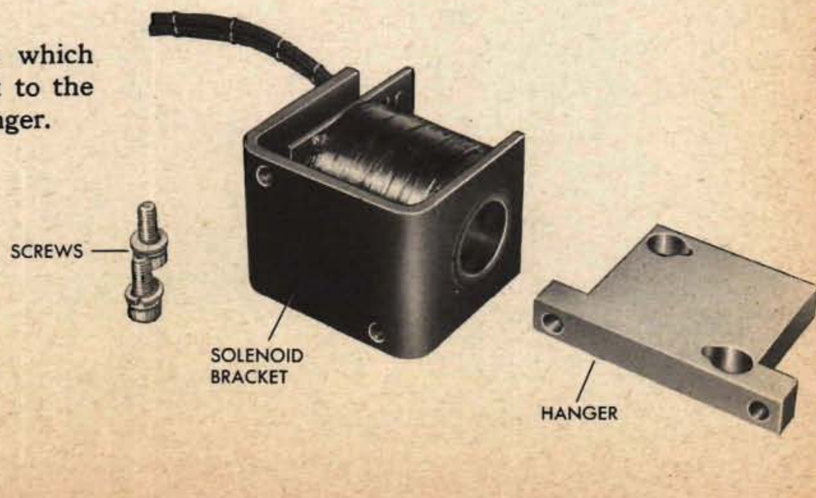


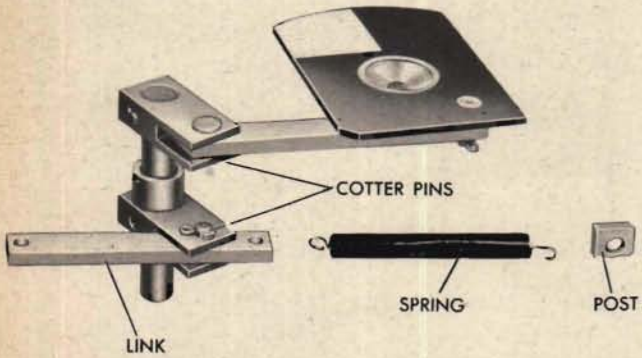
To disassemble the solenoid:

1 Pull out the plunger.



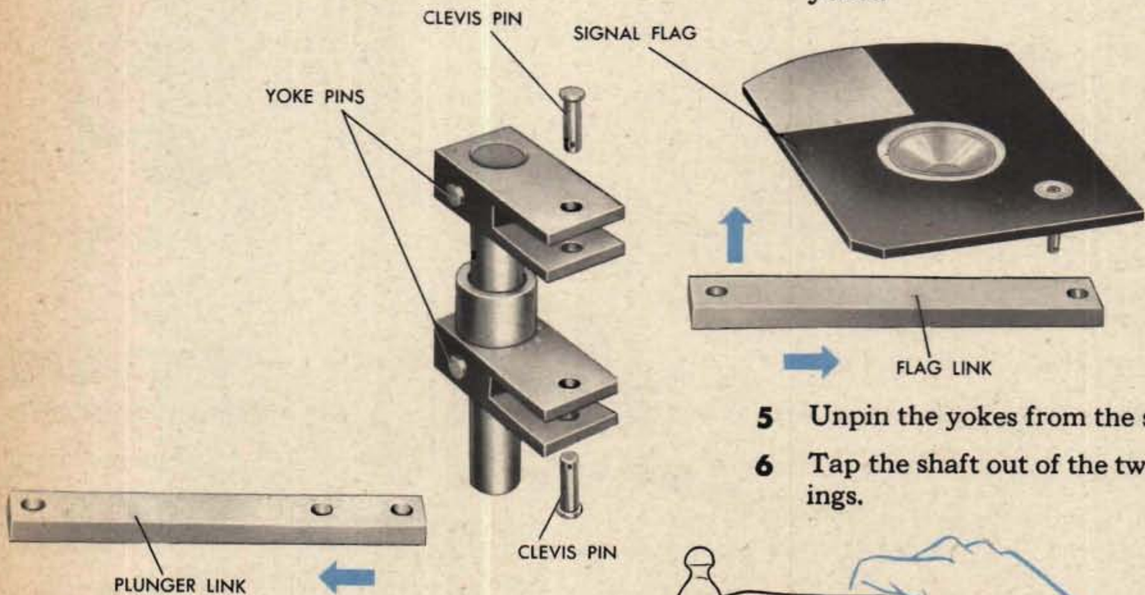
2 Remove the two screws which hold the solenoid bracket to the hanger and lift off the hanger.



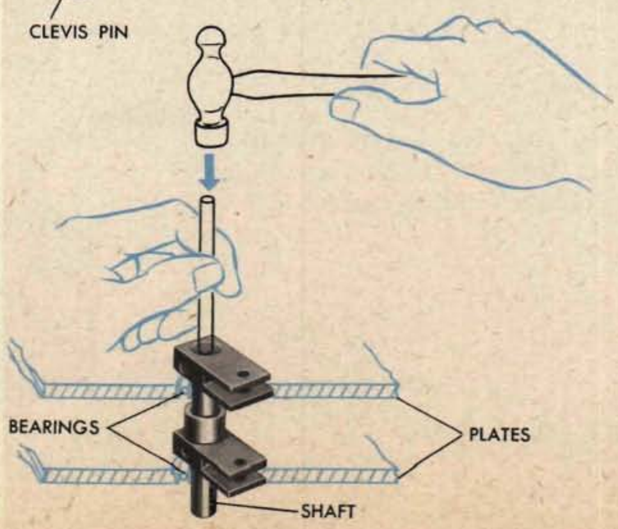


To disassemble the solenoid signal linkage:

1. Unhook the spring from the post and link.
2. Remove the three cotter pins.
3. Removal of the signal flag depends on the type of construction. Where the flag is mounted on a fixed stud, remove the snap ring and lift the flag off the stud. Where the flag hub is pinned to a bearing-mounted shaft, drive the taper pins out of the hub and collars and slide the shaft out of the parts.
4. Push out the two yoke pivot studs and separate the link from the yokes.



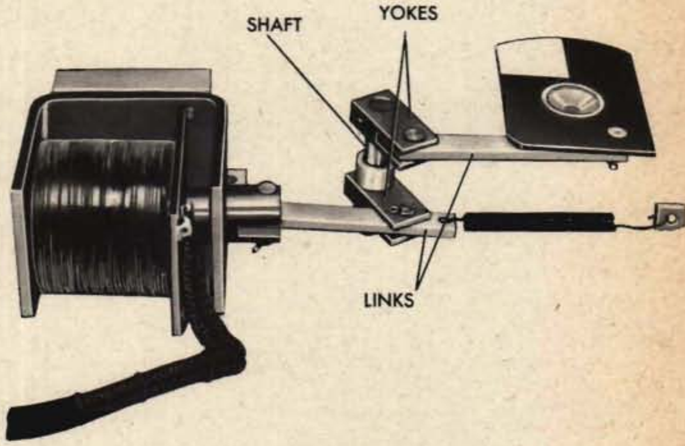
5. Unpin the yokes from the shaft.
6. Tap the shaft out of the two bearings.



Repairing the parts

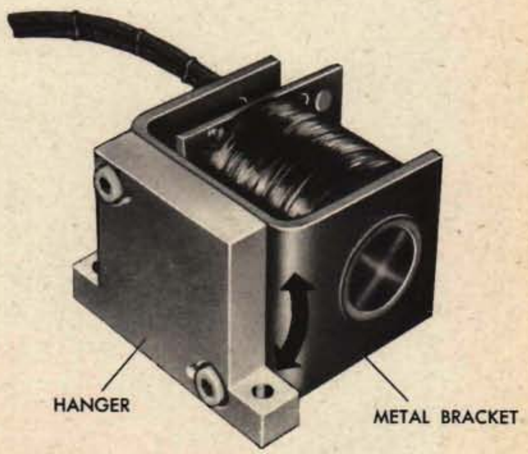
Repairing a bent shaft or link

A badly bent or damaged shaft or link must be replaced. If it is only slightly bent, remove and straighten it. Before reassembly, smooth all surfaces by polishing. Keep trying the shaft in the yokes and bearings until a good fit is obtained.



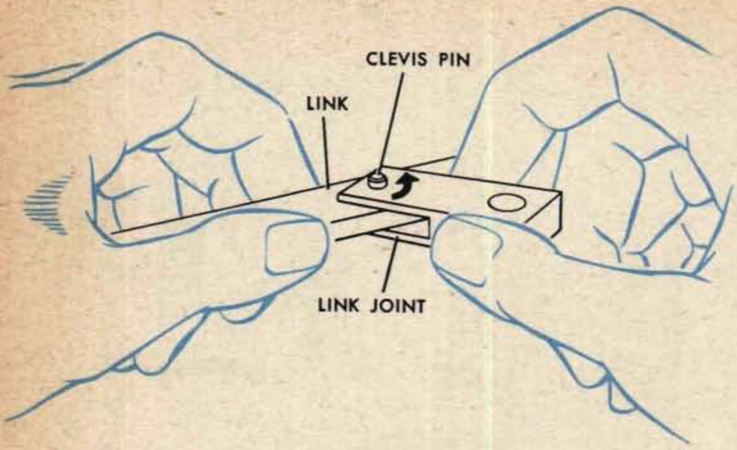
Aligning a cocked solenoid

Chattering in the solenoid usually means that the solenoid is cocked. To re-align a solenoid, first try to adjust the position of the metal bracket supporting the coil. Shift the metal bracket slightly on the hanger. If this does not align the solenoid, reposition the hanger.



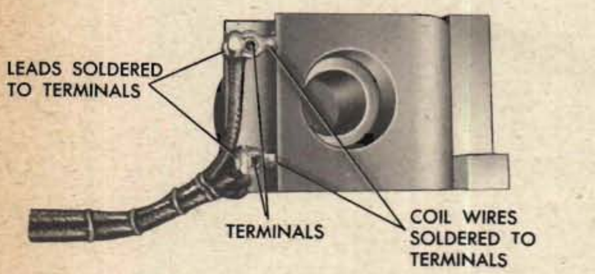
If the solenoid still chatters, check to be sure that the bottom of the hanger sets squarely on the plate.

Never ream out the core in order to eliminate chattering.



Repairing a link joint

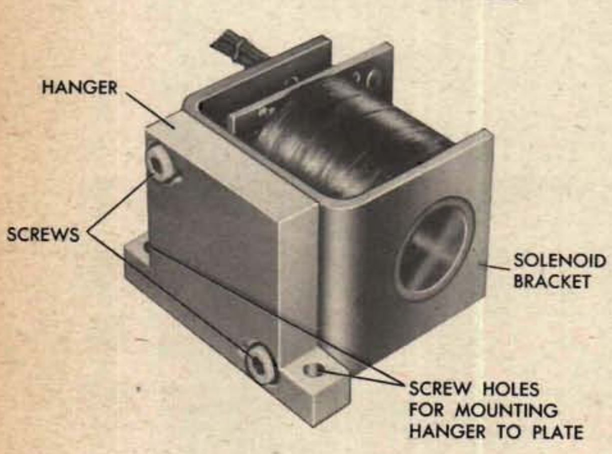
Stiffness in a link joint may be caused by either of two faults: the link binding in the yoke slot, or the clevis pin binding in the hole. The four flat working surfaces of the joint may be freed by rubbing them on a fine flat file. Remove just enough metal to eliminate burrs and obtain a free fit. If a clevis pin binds, it should be polished to remove any roughness, and the hole should be cleared of score marks and burrs by means of the correct size of reamer.



Repairing electrical parts

Electrical trouble can sometimes be repaired by disassembling the solenoid alone. A loose or open wire at a terminal can be repaired by resoldering it to the terminal. A loose terminal can be reriveted.

Never try to repair a coil with an internal break. A coil that is burned out or has an internal break must be replaced. Consult the chapter on wiring before making any electrical repairs.



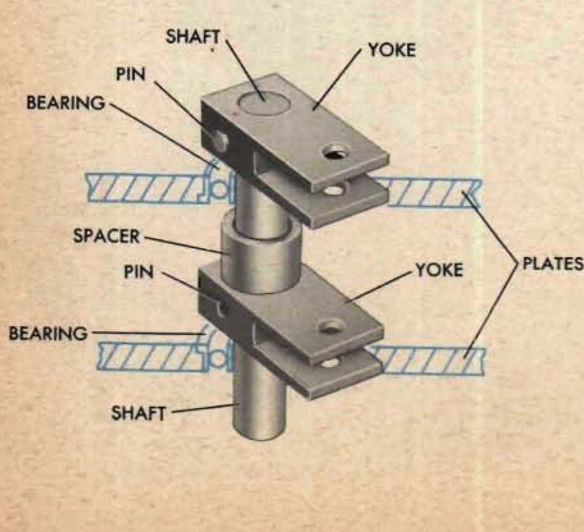
Reassembling the unit

1 Mount the solenoid bracket on the hanger and fasten the two screws.

2 Mount the solenoid in the instrument by fastening the screws which hold the hanger to the plate.

3 Mount the shaft through the two bearings in the plates and through the two yokes and spacer.

4 Pin the yokes to the shafts.

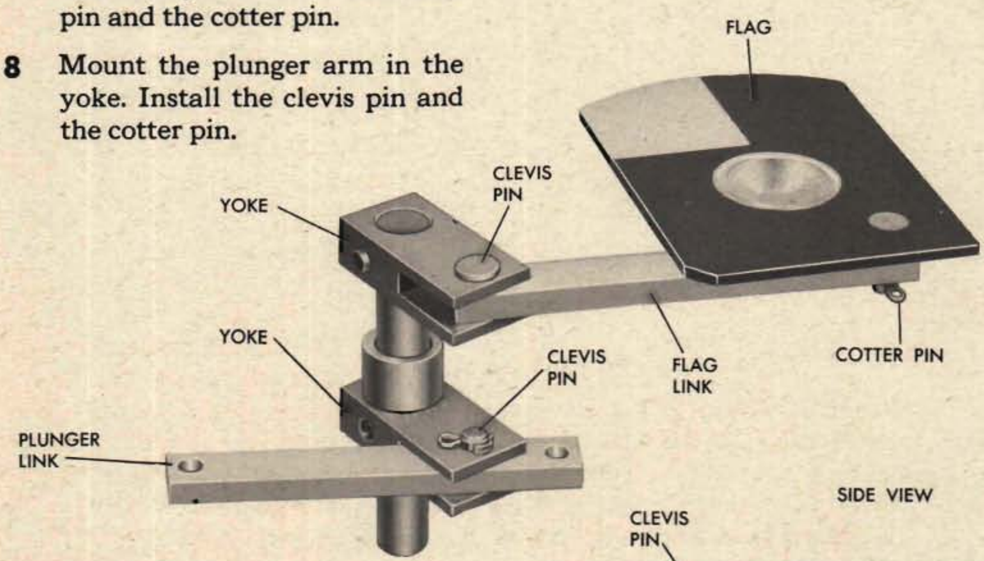


5 Join the flag and flag link and fasten them with the cotter pin.

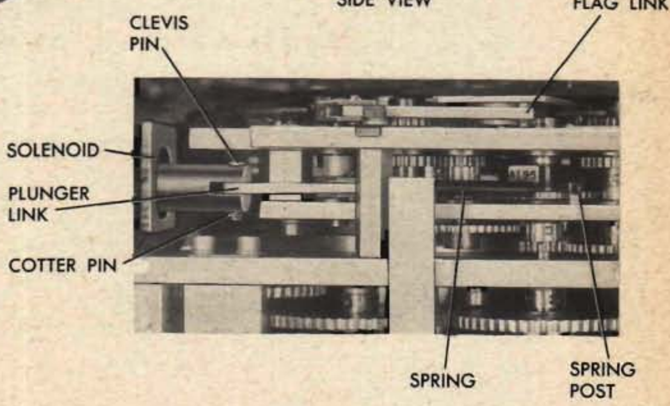
6 Replace the signal flag and secure it.

7 Mount the other end of the flag link in its yoke. Install the clevis pin and the cotter pin.

8 Mount the plunger arm in the yoke. Install the clevis pin and the cotter pin.



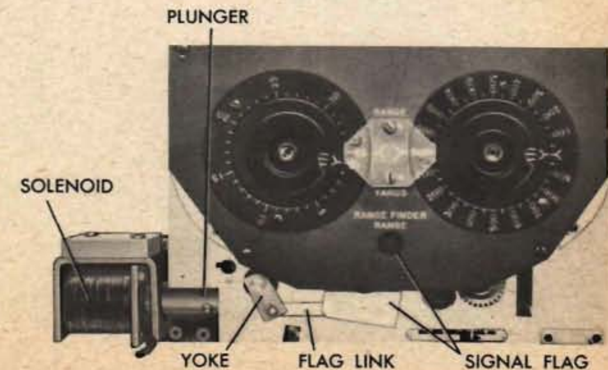
SIDE VIEW



9 After the solenoid signal linkage has been mounted in the instrument, connect the plunger link to the plunger by installing the clevis pin and the cotter pin.

10 Fasten the spring to the post and to the plunger link.

TOP VIEW



Bench checking the unit

1 The linkage must operate freely.

2 Check the wiring for continuity.

3 Test the solenoid action by supplying an independent 115-volt A.C. to the coil terminals. Do not mistake an a-c hum for chatter.

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